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INFLUENCE OF INDUSTRIAL, MUNICIPAL, & PRIVATE WASTES ON WATER QUALITY  
OF A PORTION OF THE UPPER CLARK FORK RIVER DRAINAGE - A RECONNAISSANCE  
STUDY

PHYSICAL CHEMISTRY SECTION

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A report of work conducted by

Department of Chemistry  
Geochemistry Section  
Montana College of Mineral Science & Technology  
Butte, Montana

in cooperation with

Montana Department of Health & Environmental Science  
Helena, Montana

and

The Anaconda Company  
Butte, Montana

January, 1974

\*Associate Professor  
Department of Chemistry  
Montana College of Mineral Science & Technology  
Butte, Montana

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## ACKNOWLEDGMENTS

The work presented in this report was conducted under a cooperative research agreement funded by the Montana Department of Health and Environmental Science and The Anaconda Company, supervised by Donald G. Willems and John G. Spindler of the above respective organizations. The cooperation of John Spindler of the Anaconda Company with respect to the liberal use of analytical data and the cooperation of Lester Ziehen of the Anaconda Company with respect to the use of the X-ray diffraction facilities is greatly appreciated. In addition, the efficient help of Larry Wegelin of the MBM&G with respect to the analysis of the samples was greatly appreciated and most essential to the study. Finally, the able assistance of Mrs. Anna Marie Holm in collecting much of the earlier data was most beneficial.



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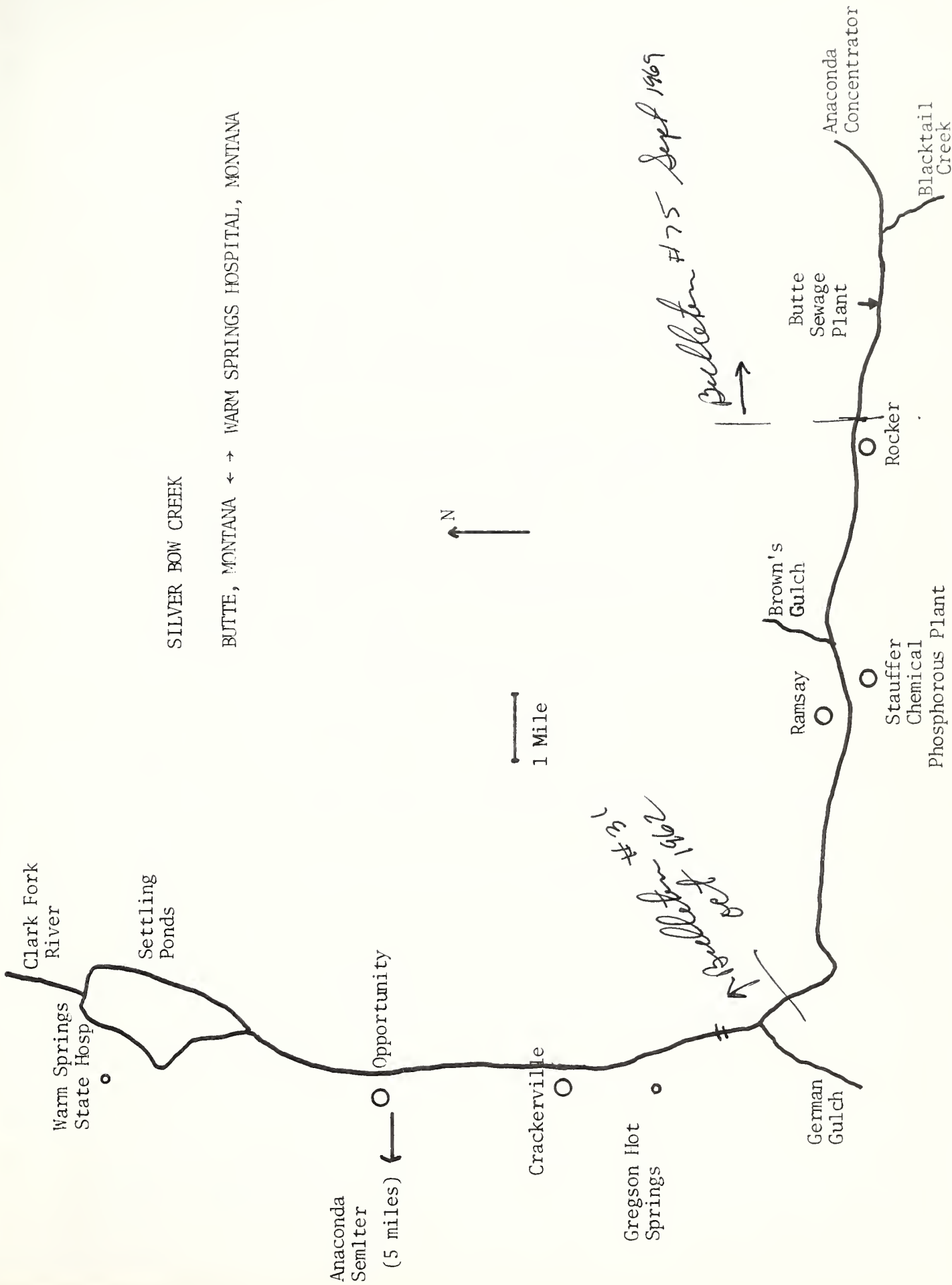
## ABSTRACT

The properties of the solid and liquid phases of Silver Bow Creek were determined and compared with the laboratory leaching data in order to describe the interaction between Silver Bow Creek sediment and relatively fresh water.

It was found that the distribution of mineral phases and the particle size of the sediment did not vary significantly along the length of Silver Bow Creek channel but did vary across the channel. The heavy metal concentration of Silver Bow Creek sediment did vary downstream as predicted by the results of the leaching experiments. The mineral phases identified by X-ray diffraction were quartz, oligoclase, orthoclase, muscovite, and pyrite. Fe, Cu, Zn, Mn, Cd, Ag, Mo, Al, Si, and Pb were determined in the water and the sediment by atomic absorption spectrometry. These sediment data along with volume rate of flow of the Silver Bow Creek and its tributaries were used for the preparation of the leaching experiments which were designed to simulate Silver Bow Creek channel characteristics. The leaching data illustrates that, if the initial concentration values in the water were sufficiently high, at a pH of approximately 7 and a temperature of 14.5°C the metal concentration of the creek water diminished with time of contact with the sediment. The comparison of these results of the leaching experiments with the Cu, Zn, Fe, Mn, Si, and Al concentrations of the actual stream indicates that there is a contribution of these cations from some source other than the Anaconda Company and the tributaries of Blacktail, Brown's Gulch, and German Gulch.

The additional factors which could effect this interpretation are the pH and temperature of the stream water and the sediment surface area to water volume ratio. It is strongly suggested that the leaching studies be continued to clarify these additional variables.





SILVER BOW CREEK

BUTTE, MONTANA ← → WARM SPRINGS HOSPITAL, MONTANA

Clark Fork  
River

Settling  
Ponds

Anaconda  
Smelter

(5 miles) ←

Crackerville

Gregson Hot  
Springs

German  
Gulch

Ramsay

Brown's  
Gulch

Stauffer  
Chemical  
Phosphorous Plant

Rocker

Butte  
Sewage  
Plant

Anaconda  
Concentrator

Blacktail  
Creek

N

1 Mile

Bullerton #75 Sept 1969

Bullerton #72 Sept 1962



## INTRODUCTION

The overall objective in this Physical Chemistry Section was to describe the interaction between pre-existing sediment and water when relatively fresh water is discharged into the Silver Bow Creek channel. This study was divided into the following two parts:

1. Determination of the physical and chemical properties of Silver Bow Creek water and sediment and of its tributaries.
2. Laboratory studies concerning the leaching of Silver Bow Creek sediment with stream water.

In order to conduct realistic leaching experiments which would reliably simulate the natural channel characteristics, sufficient physical and chemical information concerning not only the Silver Bow Creek sediment and water but also the water of its tributaries must be known. The physical data are the following:

Determination of the temperature and rate of flow of Silver Bow Creek and its tributaries as a function of time.

Identification of phases present in Silver Bow Creek sediment as a function of distance from the Anaconda Operations to the settling ponds.

Determination of the distribution of particle sizes along Silver Bow Creek channel.

The chemical data are as follows:

Inorganic chemical composition of the water of Silver Bow Creek and its tributaries.

Inorganic chemical composition of Silver Bow Creek sediment.

The collection of samples, both water and sediment, and the determination of temperature, rate of flow, and chemical composition were



primarily the responsibility of and is reported by the Montana Bureau of Mines and Geology (MBMG). The determination of size distribution and the identification of phases present in Silver Bow Creek sediment were the responsibility of the chemistry department of Montana College of Mineral Science and Technology and is reported in this Physical Chemistry Section of the report.

The laboratory studies were designed as leaching experiments in which Silver Bow Creek sediment was in contact with an aqueous solution that is continuously recirculated for a specific time interval and temperature. The initial basic assumption for the experimental model was that there would be no effluent from the Anaconda Operations entering Silver Bow Creek and that all of Silver Bow Creek water entering from the north would be entirely consumed by the mining and mineral dressing operations. This means that Silver Bow Creek south of the Anaconda Operations would begin with the relatively small input from Columbia Gardens Creek and would flow south to the successive intersections with Blacktail Creek, Chinaman's Spring, Brown's Gulch, and German Gulch. Thus the first series of leaching experiments were designed to use only Blacktail Creek water as the initial leachant. After submission of the June 8, 1973 progress report it was learned that The Anaconda Company was no longer planning on zero input but would continue to egest some liquid into Silver Bow Creek. This input would be at a variable volume but at a relatively constant concentration of dissolved solids that would be lower than in the past. Thus a new series of leaching experiments were designed in which the initial leachant was a combination of Silver Bow Creek water and



Blacktail Creek water. The sediment that was leached was determined to be Silver Bow Creek sediment at the intersection with Blacktail Creek. This was based on the evidence that the relationship between phase and particle size distribution did not change significantly along the extent of Silver Bow Creek. The temperature selected for the leaching experiments was that approximating the average of the winter and summer months. The physical relationship between the water and the sediment is difficult to reproduce in the laboratory, especially with respect to the relative contribution of the diffusion of dissolved constituents to the overall kinetics. Therefore two leaching apparatus were designed; one in which the leaching solution was continuously circulated through a column of sediment (the flow-through, FT, vessel) and the other in which the leaching solution was continuously recirculated over the sediment (the flow-over, FO, vessel). In the first type the effect of diffusion on the overall kinetics is relatively small, whereas it has a marked effect in the second type. Due to the inability to simulate the turbulence of the stream, it is proposed that the natural situation in the stream is something between the two sets of leaching data.



## EXPERIMENTAL PROCEDURE

### PROPERTIES OF CREEK WATER & SEDIMENT

#### 1. Temperature, Rate of Flow, and Chemical Composition of Silver Bow Creek and Its Tributaries

As noted above the procedure for sample collection and the determination of these data were the primary responsibility of and will be reported by the MBM&G. In addition to the data of the MBM&G, the investigators conducted a series of experiments with two objectives in mind; one designed to obtain the experimental precision for the sample preparation and the chemical analysis of the MBM&G and the other to discern the validity of the procedure in obtaining representative samples of the sediment for chemical analysis. For each of three locations on Silver Bow Creek (sites #13, #32, #33) five sediment samples were taken across the channel. Each sample was mixed by three passes through a sample splitter and then split into eight separate samples by successive passes again through the sample splitter. Each of these eight samples for each of the 15 original sediment samples were then ground on a Bleuler Mill for approximately two minutes. Between each sample the mill was cleaned by grinding  $\text{SiO}_2$  for 30 seconds. The samples were then submitted to the MBM&G for chemical analysis of the Cu, Pb, Zn, Mo, Fe, Al, & Cd content. The standard deviations of the data for each of the 8-sample sets were calculated. The sample numbers can be correlated with specific locations by referring to Table 1. The data for the chemical analysis is presented in Table 2. Sample sets  $13_1 - 13_2 - 13_3 - 13_4 - 13_5$ ,  $32_1 - 32_2 - 32_3 - 32_4 - 32_5$ , and  $33_1 - 33_2 - 33_3 - 33_4 - 33_5$  represent the five sample locations across the channel at the three sample sites. The mean concentration, variance, and standard deviation is for the eight samples representing each of these sample locations across the channel.



## 2. Particle Size Distribution of Silver Bow Creek Bottom Sediment

In order to ascertain if a significant change of particle size distribution with respect to mineralogy did occur along the Silver Bow Creek channel, samples of the sediment were collected at approximately mid-channel at various locations. The samples, collected by the MBM&G, were oven dried at approximately 50°C and approximately 1/8 of the sample, obtained with a sample splitter, was subjected to a sieving analysis in a Rotap for 15 minutes. The data is presented in Table 3. In addition, in order to discern whether the observed differences were valid, a sieving analysis of the same sample was designed to yield the experimental precision, calculated as standard deviation, which is also presented in Table 3.

In addition to the above noted sieving analysis, a representative sample of the total sediment and a sample of the smaller size fraction (<62u) were chemically treated to remove any carbonate, iron oxide, and organic residue that might act as cementing material for the smaller size fractions. Flotation of the samples after treating with  $H_2O_2$ , NaOAc, and Na citrate did not yield any clay size fraction. But since prior grinding of the sample or prior treatment in an ultrasonic generator did result in flotation of the clay size fraction, it was determined that such clay sized minerals are tied up in the large size fractions. Thus the influence of increased surface area for various minerals of this clay size fraction is not significant with respect to the leaching experiments.

## 3. Mineral Phases Present in Silver Bow Creek Bottom Sediment

Each of the size fractions of the sediment at site 13 were prepared for X-ray diffraction study by grinding and mounting on a glass slide as a water suspension slurry. By comparison of the X-ray diffraction patterns



for the various size fractions it was concluded that X-ray study of the <62u and that between 590u - 500u would be sufficient for identification of the mineral phases.

X-ray diffraction patterns were obtained for these size fractions of the sediments at the following sample sites along Silver Bow Creek; #'s 9, 12, 13, 14, 15, 18, 27, & 33. In addition, X-ray patterns were obtained for the size fraction between 590u - 500u for the tributaries, i.e., #'s 19, 21, 24, 26, 28, & 34. The mineral phases observed within Silver Bow Creek sediment are noted in Table 4.

#### LEACHING EXPERIMENTS

##### 1. Sample Collection

a. Liquid Samples: The stream water was collected in 1 liter polyethylene containers which had been previously rinsed with reagent grade concentrated  $\text{HNO}_3$ , three times with demineralized water, and finally with the stream water. The bottles were filled completely to the top and a plastic wrap placed between the screw cap and the bottle. The samples of creek water were used within 48 hours for the leaching studies. The following are the dates the corresponding streams were sampled:

Silver Bow Creek		<u>Stream Condition</u>
Dec. 29/73	2:00 PM	High Flow
Dec. 31/73	4:30 PM	Low Flow
Jan. 3/73	10:00 AM	Low Flow
Blacktail Creek		
Dec. 31/73		
Jan. 3/74		
Brown's Gulch		
Dec. 29/73		
German Gulch		
Dec. 29/73		

b. Sediment Samples: Silver Bow Creek sediment was sampled just below the intersection with Blacktail Creek. The sample was collected in



a small plastic container and placed in a large 1 gal plastic bucket. The sample represented a continuous channel cut about 3 - 5 inches deep taken across the stream. The sediment was collected within 8 hours of its use in the leaching experiments. It was left completely covered with creek water, capped with plastic wrap, and stored in an ice-water bath. Prior to its use in the leaching experiments, the sediment was thoroughly mixed with a wooden ladle.

## 2. Leaching Procedure

a. Description of Leaching Vessels: As noted above, in order to simulate the characteristics of the Silver Bow Creek channel, i.e., sediment surface area to water volume ratio and rate of transport of dissolved constituents, two leaching vessels were designed. These vessels are illustrated in Figure 1. The flow-through, FT, vessel consists of a 600 ml buchner funnel with medium fritted disc and a 500 ml 3-neck boiling flask. The sediment is retained in the buchner funnel and approximately 900 ml of solution is in the total system. The solution is circulated through the sediment at a rate controlled by an air bubbler in which the solution is replenished by a siphon. The flow-over, FO, vessel consists of an approximately one meter long and 6 cm diameter glass tube in which the sediment is placed. This tube is inclined at an angle and connected to the 500 ml 3-neck boiling flask by way of a siphon. The solution is returned to the boiling flask by either a peristaltic or vibrating pump.

b. Leaching Run: Prior to their use the leaching vessels were rinsed once with reagent grade concentrated  $\text{HNO}_3$ , three times with de-mineralized water, and once with the leachant. Two series of leaching experiments were conducted, each of which simulated wither high or low flow conditions in Silver Bow Creek. Duplicate FT and FO vessels



were used and the solution was circulated at constant but different rates. This rate for a specific vessel was the same for the high and low flow leaching series. The characteristics of each vessel are described below:

	<u>Water Circulation</u>		Continuous pH
	<u>Method</u>	<u>Rate</u>	<u>Record</u>
FT Vessel			
#1	air bubbler	0.018 l/min.	yes
#2	air bubbler	0.012 l/min.	no
FO Vessel			
#3	peristaltic pump	0.032 l/min.	no
#4	vibrating pump	0.46 l/min.	yes

Each leaching run with the FT vessel consisted of the following procedure.

Approximately 300 ml of sediment, as measured in a previously rinsed graduated beaker, was placed in the buchner funnel and the solution removed by applying suction with a water aspirator for approximately 3 minutes. The buchner containing the sediment was then attached to the boiling flask and the apparatus filled with 908 ml of an appropriate mixture of Silver Bow Creek and Blacktail Creek water. These volumes, listed in Table 5, were calculated from the measured rates of flow of the streams, which are tabulated in Table 6. A 10 ml sample of the leachant was taken from the top of the buchner funnel with a pipet and this time noted as zero time for the run. The siphon and bubbler were then primed by applying air pressure at the open end of the boiling flask. The vessel was placed in the constant temperature bath, the pH probe inserted into the tip of the buchner funnel, and the circulation of leachant initiated by attaching the air line. Succeeding 10 ml samples of leachant were removed by pipet at various times. After 5 hours and 36 minutes the vessel was removed from the water bath and the leachant removed from the vessel and sediment (the latter by suction for approximately 3 minutes). A mixture containing the appropriate volumes of this first leachant and



Brown's Gluch Creek water was placed in the vessel. The apparatus was placed in the constant temperature bath, the pH probe inserted, and the circulation of the new leachant initiated. This second part of the leaching run was continued for 3 hours and 26 minutes at which time the vessel was removed from the bath and a new leachant placed in the vessel. This solution was a mixture of the second leachant and German Gulch water. This third part of the leaching run was terminated after 3 hours and 48 minutes. The leaching times for each part of the leaching run were calculated from the average velocity of and distances along Silver Bow Creek between its intersections with Blacktail Creek, Brown's Bulch, and German Gulch. This average velocity was taken from the velocities measured by the MBM&G at a depth of 1/3 up from the sediment-water interface at various sample sites. The frequency of sampling the leachant was choosen to be every 30 minutes for the first two samples and thereafter every hour for each of the three parts of the leaching run. The initial 30 minute interval was choosen upon the assumption that the largest effects would occur early in the leaching period. This assumption was validated by the data.

The leaching procedure for the FO vessels was identical to that of the FT vessels with the exception of handling the sediment. Instead of placing the sediment in a buchner funnel and removing the liquid by suction, the sediment was placed in the long tube and the liquid drained from the solid prior to filling the FO vessel with the initial leachant.

A blank leaching run was performed in a FT and a FO vessel. The procedure was identical to that noted above except that no sediment was used. The 10 ml samples of the leachant taken during the leaching runs were stored in small polyethylene screw-cap vials. The vials had been previously rinsed once with reagent grade concentrated  $\text{HNO}_3$ , rinsed three times with demineralized water, and dried with spectrographic grade acetone.



Two drops of concentrated  $\text{HNO}_3$  (Baker #9603 - suitable for mercury determination) were added to each 10 ml leachant sample, which was then sealed in the vial with plastic wrap placed between the cap and bottle. The samples were analyzed for Cu, Fe, Zn, Mn, Si, and Al on a Perkin Elmer 503 AA by the MBM&G.



## DISCUSSION OF RESULTS

### PROPERTIES OF CREEK WATER AND SEDIMENT

#### 1. Temperature

The temperatures of the Silver Bow Creek water as measured by the MBM&G with respect to different sampling dates are noted in Table 7. The temperature selected for the leaching experiments was 14.5°C. This was the lowest temperature attainable due to the large volume of water in the two water baths and the available cooling apparatus.

#### 2. Rate of Flow

The pertinent rates of flow as measured by the MBM&G are noted in Table 6. These rates of flow were used to calculate the volumes of Silver Bow Creek and the tributaries used for the leachant solutions.

#### 3. Chemical Composition of Silver Bow Creek Sediment

a. Validity of MBM&G Sampling Procedure: The sediment sampling procedure was based upon the assumption that a mid-channel sample would be representative of the chemistry of the sediment along the length of Silver Bow Creek. Comparison of the composition of the mid-channel samples and the mean of the five samples across the creek with that for another sample site illustrates that the mid-channel sample is not representative of the sediment chemistry. See Table 8. It is apparent that in order for the chemical analysis to be representative of the sediment at a sample site, a continuous channel sample perpendicular to the stream must be taken and appropriate sample mixing and splitting performed prior to chemical analysis.

b. Composition Across the Channel: As noted in Table 2 the composition of the metals tend to increase outward from the center of the channel in all of the three sample sites (#13, #32, #33). It has been observed by the MBM&G personnel that the changes of flow of Silver Bow Creek usually did not correlate with corresponding flow data for the tributaries.



Thus it is assumed that the high flow coorelates with the input from the Anaconda Company. If this assumption is correct, then it seems reasonable that with a high influx of dissolved and suspended matter and high flow, the higher concentrations of metal in the sediment should be found at the boundaries of the channel.

c. Composition Along Length of the Channel: It is observed in Table 9 that the concentration of Cu, Pb, Zn, Mo, Fe, Ag, & Cd decrease downstream and Mn and Al increase. The explanation of this trend is directly related to an interpretation of the leaching studies and will be discussed in a later section of this report. In addition, the composition of most of the metals do not decrease to a great extent from just upstream to downstream of the settling ponds. In contrast, the concentrations of Zn, Fe, and Al increase across the settling ponds. But it should be pointed out that the experimental precision for the concentration of Fe and Zn are very close to the magnitude of these differences across the ponds. The relatively small decreases for most of the cations across the ponds is probably due to the lower sediment surface area to water volume ratio and will be discussed in greater depth in a later section of this report.

#### 4. Chemical Compostion of Silver Bow Creek Water

The MBM&G personnel observed large variations in the volume rate of flow of the creek and this phenomenum would occur within a few hours. Since the data required for comparison with the leaching data must be that for the same quantity of water moving downstream, the investigators in this Physical Chemistry Section had to resort to data collected by the Anaconda Company, These concentration data were reportedly obtained from samples which were taken from the same quantity of water as it moved downstream.



## 5. Silver Bow Creek Sediment Particle Size Distribution

The following points relate to the size distribution data noted in Table 3.

There is a marked increase in percent of the sediment in the size range <500u in Silver Bow Creek after the intersection with Blacktail Creek. Since Blacktail Creek seems to be relatively heavy in this size fraction, this effect in Silver Bow Creek probably represents the influence of this tributary.

There is a marked increase in the size fractions <125u in Silver Bow Creek just above German Gulch. This does not appear to be due to a lowered velocity of the stream since this site has a flow rate of 141.18 ft<sup>3</sup>/sec with a 27 ft wide channel whereas upstream the flow rate is 121.26 ft<sup>3</sup>/sec with a 40 ft wide channel. A possible explanation could be the influence of Chinaman's Spring and Brown's Gulch, for which there is not any size distribution data.

There does not appear to be any significant difference in the size distribution in the Silver Bow Creek sediment above and just below the Anaconda operations (sites #9 and #12). This at first glance appears unusual, if the Anaconda effluent does add a measurable amount of suspended material. Thus it would appear that the particle size of the suspended solids in the effluent and the velocity of the stream are such that these solids are transported to and drop out in the settling ponds. In addition, the Silver Bow Creek sediment contains much less material in the lower size fraction just below the settling ponds than just above the ponds. This further illustrates that the smaller size fractions are in fact dropping out in the ponds.



## 6. Mineralogy vs Size Fraction in the Silver Bow Creek Sediment

It was observed that the mineralogy associated with the size fractions of between 590u & 500 and <62u did not change in kind but only amount downstream. Thus it was assumed that the sediment used for the leaching experiments could be taken just below the intersection with Blacktail Creek. There have been no mineral phases identified for any of the observed heavy metals except for Fe. It is possible that the concentrations of such unidentified phases are so low as to be not discernable with X-ray diffraction. Other possibilities are that the heavy metals are either included within the structures of the identified phases, e.g., Cu in solid solution with Fe in pyrite, or that they are adsorbed on the surfaces of the identified phases. It should be noted that, with respect to the adsorption and ion exchange processes, the clay size minerals are small in amount and are tied up in the large size fractions.



## LEACHING EXPERIMENTS

### 1. Leaching Data

The concentration of Fe, Cu, Zn, Mn, Si, and Al in the leachant, corrected for the loss of previous samples, are plotted as a function of leaching time in Figures 2 through 24, respectively. The data from the FT #1 and the FO #4 vessels are denoted by a dot and that from the FT #2 and the FO #3 vessels are denoted by an open circle. The experimental precision for these data are  $\pm 4\%$  of the amount reported. There were no corrections of these data required by the results of the blank runs, i.e., the changes in concentration of Fe, Cu, Zn, Mn, Si, and Al observed in the blank runs were insignificant with respect to the concentration changes noted in the leaching data. The abrupt increases in concentration clearly illustrates the initiation of the three parts of the leaching run. As noted above, the 1st part is that which has Silver Bow Creek plus Blacktail Creek as the leachant, the 2nd part has the 1st leachant plus Brown's Gulch and 3rd. part has the 2nd leachant plus German Gulch. This abrupt increase in concentration upon changing the leachant can not be explained by the concentration of cations in the tributaries, as noted below.

Concentration (mg/l)	<u>Fe</u>	<u>Cu</u>	<u>Zn</u>	<u>Mn</u>	<u>Si</u>	<u>Al</u>
Brown's Gulch	.01	.02	.02	.01	14.5	.1
German Gulch	.01	.02	.02	.01	8.1	.1

No explanation of this change in concentration upon changing the leachant is offered at this time, but it is believed that these concentrations are real and not the manifestation of some effect, such as absorption of radiation in the AA flame due to suspended matter. This point is supported by the concentration of the tributaries noted above. In addition, the pH changes noted below during the entire leaching runs do not shed any light on this dilemma. This record of pH was obtained only for the FT



vessel #1 and the FO vessel #4.

pH for Stream Contions of		Low Flow				and	High Flow			
		FT		FO			FT		FO	
		start	end	start	end		start	end	start	end
Part 1		8.7	7.8	8.3	8.1		7.6	7.6	6.6	7.3
Part 2		7.5	7.7	8.4	8.4		7.6	7.6	7.6	7.6
Part 3		7.6	7.6	8.4	8.4		7.6	7.6	7.6	7.6

The important point is that in all 4 vessels and for all 3 parts of each leaching run, regardless of whether it represents either low or high flow conditions in Silver Bow Creek, the concentration of the cations in the leachant decrease with time. This means that the interaction between the sediment and stream water is not that of contributing cations to the solution but just the reverse. An adsorption process instead of a precipitation process is indicated as being responsible for this phenomena. This choice of processes is based upon the effect of the leachant circulation rate upon the extent of cation decrease.

The extent of what appears to be an adsorption process, i.e., the adsorption capacity of the sediment, is indicated by a comparison of the minimum concentration attained in the leachant for the same circulation rate but for different initial concentrations. This data, illustrated below, is that for the 1st part of the leaching run and for the FT vessel #1. The values reported are the initial and the minimum concentration attained at the end of the 1st part of the leaching run, i.e., just prior to changing the leachant.

Cation Concentration (Part 1) (FT Vessel) (Initial/Final)  
for Silver Bow Stream Conditions of Low Flow and High Flow.

Fe	1.7/0.03	17/0.03
Cu	0.18/0.014	2.5/0.034
Zn	0.5/<0.01↓	7.0/0.1 ↓
Mn	0.57/0.1	4.7/0.94↓
Si	8.7/5.3↓	17/5.5↓
Al	0.27/0.037	2.4/0.044↓



The FT vessel #1 was chosen since this vessel had the largest sediment-solution contact due to the solution flowing through the sediment and the higher leachant solution circulation rate of the two FT vessels. Thus there was a relatively high probability of reaching a constant minimum cation concentration in the leachant within the leaching time for the 1st part of the leaching run. The few exceptions to this assumption are noted by arrows written after the minimum concentration values to denote that the rate of change of concentration with time was still a negative value at the end of the 1st part of the leaching run. It is observed that Fe, Si, and Al are the only cations that had reached the approximate same value within this time interval and that an initial concentration that is 10 times greater than that for the low flow experiment does not alter the constant minimum concentration attained. The data for Cu and Zn indicate that an increase of the initial concentration by a factor of ten results in a higher constant minimum concentration in the leachant. Thus it would appear that Fe is preferentially adsorbed and that a higher initial concentration of Fe decreases the amount of Cu and Zn that can be adsorbed from the solution. If the high-flow, FT, part 1 curve for Mn would be extrapolated to a much longer time interval, it appears to approach an approximate constant minimum value of 0.1 mg/l, the same as that attained within the time scale of part 1 for the low flow, FT Mn curve. The reason for the delay with respect to reaching this constant minimum value for Mn is not known.

For all the cations the rate of change of concentration was larger and the minimum value reached was lower for the FT vessels. This is the result one would predict on the basis of the magnitude of the contact between the solution and the solid. Based on this effect of solid-solution contact and the assumption that the process is adsorption, it would appear that the diffusion of the cations through the aqueous phase to the solid surface is



rate controlling.

The effect of rate of flow of the leachant either through or over the sediment is itemized below for each element. The vessel noted is the one in which the element concentration changed the greatest amount in the shortest period of time. As explained above, vessels #1 and #2 are the FT vessels and vessels #3 and #4 are FO vessels. Since vessel #1 had a higher leachant circulation rate than #2 and that in vessel #4 was greater than in #3, one would expect a more significant change in cation concentration in vessels #1 and #4 compared to #2 and #3, respectively. This assumption appears to be validated by the data for most of the cases. No explanation is offered at this time for the exceptions.

Silver Bow Stream Condition		Low Flow			High Flow		
Part of Leachin run		<u>1</u>	<u>2</u>	<u>3</u>	<u>1</u>	<u>2</u>	<u>3</u>
Fe	FT	#1	#1	#1	#1	#1	#1
	FO	=	#4	#3	#3		
Cu	FT	#1	#1	#2	#1	#1	#1/#2
	FO	=	#4	#3	#3		
Zn	FT	#1	#1	#1	#1	#1	#1/#2
	FO	#3	#4	#4			
Mn	FT	#1	=	=	#2	#2	#2
	FO	#3	#4	#4	#3		
Si	FT	#1	#1	#2	#1	=	#2
	FO	=	#4	#4	#3		
Al	FT		?	#1	#1	#1	?
	FO	#3	#4	#4	#3		

## 2. Comparison of Leaching Data with Stream Data

As noted in the discussion above the important point stemming from these leaching studies is that the adsorption of Fe, Cu, Zn, Mn, Al, and Si onto the sediment surface results in a decrease in the concentration of the cations in the leachant. This phenomenon must be put into the proper perspective in that it was observed when the pH was between 6.6 and 8.7 and for the specific



ratio and absolute values of cation concentration in the leachant. The assumption is that the actual stream conditions are simulated by the leaching experiments. The major problem in simulating the stream is not only with respect to temperature, pH, and cation concentration but also with respect to the rate of transport of dissolved constituents to and from the solid surface. The FT vessels are considered to represent the stream conditions in which there is a maximum transport rate due to the solution passing through the sediment. The FO vessels would represent the minimum transport rate and thus a situation in which the sediment-water interaction would be retarded to the greatest extent due to the requirement of the diffusion of cations through the solution phase. Thus, due to the turbulence of the stream that is not simulated in the FO vessels and a much higher sediment-water contact in the FT vessels, it is assumed that the actual Silver Bow Creek channel characteristics are represented by an average of the conditions in the two types of vessels.

The application of the leaching data to the stream data is illustrated by the following arguments pertaining to the values of Cu concentration. As previously noted, the analytical stream data that must be used are those that were determined from the same quantity of water as it moves downstream, namely, the stream data determined by the Anaconda Company. The data for August 7, 1973 will be used as an example for comparison with the leaching data for Cu. The measured Cu concentration at various sample sites in Silver Bow Creek are plotted in Figure 29.

The first consideration is to calculate the change in concentration of Cu in Silver Bow Creek due its mixing with Blacktail Creek. The average flow conditions in Silver Bow Creek on August 7 are noted in the Anaconda Company data noted below.



<u>Average Anaconda Input</u> MGD		<u>Assumed Flow Conditions</u>
Aug. 1	0	low flow
Aug. 7	0.935	low flow
Aug. 13	14.39	high flow
Aug. 14	5.97	intermediate flow

The maximum and minimum concentrations of the cations in the tributaries as measured by the MBM&G are presented in Table 10. Since the flow conditions in Silver Bow Creek on August 7th have been interpreted as low flow, the volumes of Silver Bow Creek water and Blacktail Creek water used for this calculation are those that were used in the low flow leaching vessels, either FT or F0. The following data result in a calculated Cu concentration of 0.63 mg/l.

	<u>Volume (ml)</u>	<u>Cu Conc (mg/l)</u>
Silver Bow Creek	363	1.55
Blacktail Creek	545	0.02

This value is plotted in Figure 29 as the calculated Cu concentration in Silver Bow Creek just downstream from its intersection with Blacktail Creek.

The second consideration is to determine the concentration in Silver Bow Creek just upstream of its intersection with Brown's Gulch by applying the laboratory leaching data. The intermediate curve for the 1st part of the leaching run in the FT low & high flow and the F0 low and high flow vessels are used to determine the final concentration through the sediment-water interaction. This is done by finding the intersection of the intermediate curves with the value of 0.63 mg/l and, if necessary, extrapolating the curves for the total leaching time for the 1st part of the leaching run. The following data are those obtained in this specific case.

		<u>Cu Concentration (mg/l)</u>			
		<u>Initial</u>		<u>Final</u>	
		<u>low flow</u>	<u>high flow</u>	<u>low flow</u>	<u>high flow</u>
FT	0.63	0.63		?	0.058
F0	0.63	0.63		?	0.43

Average = 0.25 mg/l

The average concentration value is accepted since it is assumed that the



actual sediment-water interaction in the stream is represented by an average of the leaching data. If the initial concentration is so high that an intermediate curve does not intersect it, then, as noted in the data above, a question mark is entered as the final concentration value. This final value of 0.25 mg/l is plotted in Figure 29 as the Cu concentration in Silver Bow Creek just upstream of its intersection with Brown's Gulch.

The third consideration is to calculate the Cu concentration in Silver Bow Creek due to its mixing with Brown's Gulch. There are two initial concentration values which should be used, namely, the actual stream concentration and the above calculated concentration. From these data, the two resultant concentrations are noted below.

	<u>Volume (ml)</u>	<u>Cu Concentration</u>		<u>Final Conc. (mg/l)</u>	
		<u>Field</u>	<u>Lab</u>	<u>Field</u>	<u>Lab</u>
Silver Bow Creek	815	0.50	0.25	0.45	0.23
Brown's Gulch	93	0.02	0.02		

These values of 0.45 and 0.23 mg/l are plotted in Figure 29 as representing the field and laboratory concentrations in Silver Bow Creek just downstream from its intersection with Brown's Gulch.

The fourth consideration is to determine the concentration in Silver Bow Creek just upstream of its intersection with German Gulch by applying the laboratory leaching data. The same procedure is used here as that described in the second consideration above, with the exception that the intermediate curves for the second part of the leaching runs are used. The data and results are noted below.

	<u>Cu Concentration (mg/l)</u>			<u>Average Final Cu Conc. (mg/l)</u>	
	<u>Initial</u>	<u>Final</u>		<u>Field</u>	<u>Lab</u>
		<u>Low Flow</u>	<u>High Flow</u>		
Field	0.13	?	0.032	0.032	0.032
Lab	0.10	?	0.032		



#### SUGGESTIONS FOR FURTHER WORK

There are additional parameters which should have an effect on the results of the laboratory leaching studies, namely, temperature, sediment surface area to leachant volume ratio, and pH of the leachant. The range of temperature of Silver Bow Creek water is within  $\pm 10^{\circ}\text{C}$  of the  $14.5^{\circ}\text{C}$  selected for the leaching experiments. It is not anticipated that a temperature change of this small magnitude would significantly alter the leaching results, but it is suggested that this be ascertained experimentally. An indication of the magnitude of the effect of sediment surface area to leachant volume ratio was observed in the comparison of composition data originating from the leachants in the FT and F0 vessels and in the FT or F0 vessels of different leachant circulation rate. Since an increase in this ratio resulted in a dramatic increase in the rate of cation removal from solution, this parameter should be further investigated. The pH of the initial leachant most certainly would have an effect upon the results of the leaching experiments. It is envisioned that a change in pH might either change the adsorption capacity of the sediment or even result in an increase in a specific cation concentration instead of the decrease observed in these leaching studies. Both of these latter variables, i.e., pH and sediment surface area to leachant volume ratio, would have a direct bearing upon later possible field tests, such as construction of an experimental channel.

Finally, the adsorption capacity of the sediment should be investigated. This parameter was observed to be a function of the ratio of the metal concentration in the solution phase. It is proposed that different amounts of the appropriate salts be added to the initial leachant to observe the effects on the minimum values obtained in the various parts of the leaching runs. The result of investigating this parameter would have a direct bearing on the



efforts of the Anaconda Company to control the concentration of these cations in their input to Silver Bow Creek.



# APPENDIX

## TABLE 1

### SAMPLING SITES

SITE #	SITE LOCATION
7	✕Blacktail Creek above Silver Bow Creek
9	Silver Bow Creek above Tailing Pond
12	Silver Bow Creek above Blacktail Creek
13	Silver Bow Creek Below Domestic manganese plant & Montana Pole Treating plant & above sewage treatment plant
14	Silver Bow Creek above Rocker
15	Silver Bow Creek between Stauffer & Ramsey
16	✕Brown's Gulch above Chinaman's Spring
17	Chinaman's Spring above Brown's Gulch
18	Silver Bow Creek above German Gulch
19	✕German Gulch above Silver Bow Creek
21	✕Gregson Creek below Gregson complex
22	Silver Bow Creek at US 10a crossing
26	✕Mill Creek above Willow Creek
27	Silver Bow Creek at Warm Springs pH shack
28	✕Warm Springs Creek above Myer's Dam
31	Warm Springs Creek at its mouth
32	Clark Fork River below Warm Springs Creek
33	Silver Bow Creek at upper pH shack
34	✕ Mill & Willow Creeks at their intersection



TABLE 2

## CHEMICAL ANALYSIS OF CROSS-CHANNEL SAMPLES

		Mean Conc. <u>(mg/l)</u>	Variance <u>(mg/l)</u>	STD. Dev. <u>(mg/l)</u>
13 <sub>1</sub>	(channel boundary)			
	Cu	3633	10498	102
	Pb	291	188	13
	Zn	700	10	3
	Mn	322	423	20
	Mo	17	3	1
	Fe	187850	13687499	3699
	Al	6838	85810	292
	Ag	7	0	0
	Cd	7	0	0
13 <sub>2</sub>	(1/4-channel)			
	Cu	3028	88410	297
	Pb	268	239	15
	Zn	664	26	5
	Mn	604	7093	84
	Mo	13	0	0
	Fe	129837	13207342	3634
	Al	5983	4573	67
	Ag	6	1	1
	Cd	9	0	0
13 <sub>3</sub>	(mid-channel)			
	Cu	2506	45973	214
	Pb	228	195	13
	Zn	643	16	4
	Mn	464	7877	88
	Mo	12	4	2
	Fe	136987	7943593	2818
	Al	6046	47098	217
	Ag	5	0	0
	Cd	9	0	0
13 <sub>4</sub>	(3/4-channel)			
	Cu	2476	6023	77
	Pb	230	347	18
	Zn	605	486	22
	Mn	376	2512	50
	Mo	12	3	1
	Fe	158750	11229999	3351
	Al	5855	126800	356
	Ag	5	3	1
	Cd	7	2	1
13 <sub>5</sub>	(channel boundary)			
	Cu	3415	41725	204
	Pb	399	6483	80
	Zn	660	600	24
	Mn	1220	83800	289



TABLE 2 (continued)

	Mean Conc. (mg/l)	Variance (mg/l)	STD. Dev. (mg/l)
13 <sub>5</sub> (channel boundary)			
Mo	19	25	5
Fe	121275	64176872	8011
Al	5172	40593	201
Ag	9	26	5
Cd	10	16	4
32 <sub>1</sub> (channel boundary)			
Cu	776	18137	134
Pb	147	254	15
Zn	679	171	13
Mn	483	4689	68
Mo	7	3	1
Fe	55412	24276091	4927
Al	6827	156493	395
Ag	3	0	0
Cd	6	0	0
32 <sub>2</sub> (1/4 - channel)			
Cu	625	8502	92
Pb	134	495	22
Zn	655	1576	39
Mn	751	5063	71
Mo	5	1	1
Fe	44417	1718096	1310
Al	9305	9251324	3041
Ag	2	1	1
Cd	3	0	0
32 <sub>3</sub> (mid-channel)			
Cu	480	3633	60
Pb	96	169	13
Zn	586	13	3
Mn	494	394	19
Mo	3	0	0
Fe	41075	8981874	2996
Al	8918	2653085	1628
Ag	1	0	0
Cd	2	0	0
32 <sub>4</sub> (3/4 - Channel)			
Cu	552	1371	37
Pb	104	182	13
Zn	606	803	28
Mn	537	980	31
Mo	4	0	0
Fe	43994	2060292	1435
Al	7777	647743	804
Ag	1	0	0
Cd	2	0	0

TABLE 2 (continued)

Element	Mean conc. (mg/L)	Variance (mg/L)	Standard deviation (mg/L)
32 <sup>a</sup> (continued)			
Co	1.1	0.0001	0.01
Cu	0.1	0.0001	0.01
Pb	0.1	0.0001	0.01
Zn	0.1	0.0001	0.01
Mn	0.1	0.0001	0.01
Mo	0.1	0.0001	0.01
Fe	0.1	0.0001	0.01
Al	0.1	0.0001	0.01
Ag	0.1	0.0001	0.01
Cd	0.1	0.0001	0.01
32 <sup>b</sup> (continued)			
Co	1.1	0.0001	0.01
Cu	0.1	0.0001	0.01
Pb	0.1	0.0001	0.01
Zn	0.1	0.0001	0.01
Mn	0.1	0.0001	0.01
Mo	0.1	0.0001	0.01
Fe	0.1	0.0001	0.01
Al	0.1	0.0001	0.01
Ag	0.1	0.0001	0.01
Cd	0.1	0.0001	0.01
32 <sup>c</sup> (continued)			
Co	1.1	0.0001	0.01
Cu	0.1	0.0001	0.01
Pb	0.1	0.0001	0.01
Zn	0.1	0.0001	0.01
Mn	0.1	0.0001	0.01
Mo	0.1	0.0001	0.01
Fe	0.1	0.0001	0.01
Al	0.1	0.0001	0.01
Ag	0.1	0.0001	0.01
Cd	0.1	0.0001	0.01
32 <sup>d</sup> (continued)			
Co	1.1	0.0001	0.01
Cu	0.1	0.0001	0.01
Pb	0.1	0.0001	0.01
Zn	0.1	0.0001	0.01
Mn	0.1	0.0001	0.01
Mo	0.1	0.0001	0.01
Fe	0.1	0.0001	0.01
Al	0.1	0.0001	0.01
Ag	0.1	0.0001	0.01
Cd	0.1	0.0001	0.01

TABLE 2 (continued)

	Mean Conc. (mg/l)	Variance (mg/l)	Std. Dev. (mg/l)
32 <sub>5</sub> (channel boundary)			
Cu	882	19583	139
Pb	140	140	11
Zn	627	1793	42
Mn	1229	32537	180
Mo	5	0	0
Fe	46767	10022309	3165
Al	9545	976049	987
Ag	2	1	1
Cd	7	1	1
33 <sub>1</sub> (channel boundary)			
Cu	546	4215	64
Pb	122	67	8
Zn	570	332	18
Mn	519	6699	81
Mo	7	2	1
Fe	34382	1426328	1194
Al	7385	534849	731
Ag	2	1	1
Cd	6	0	0
33 <sub>2</sub> (1/4 - channel)			
Cu	703	323	17
Pb	130	27	5
Zn	582	29	5
Mn	1138	167	12
Mo	12	2	1
Fe	31374	1488024	1219
Al	4551	365460	604
Ag	3	0	0
Cd	5	0	0
33 <sub>3</sub> (mid channel)			
Cu	770	85	9
Pb	148	7	2
Zn	625	19	4
Mn	1470	211	14
Mo	16	4	2
Fe	39476	220353	469
Al	4673	442448	665
Ag	4	0	0
Cd	4	0	0



TABLE 2 (continued)

	Mean Conc. (mg/l)	Variance (mg/l)	Std. Dev. (mg/l)
33 <sub>4</sub> (3/4 - channel)			
Cu	906	4987	70
Pb	215	7829	88
Zn	644	137	11
Mn	736	8024	89
Mo	12	25	5
Fe	52912	6556605	2560
Al	7711	138860	372
Ag	3	0	0
Cd	12	0	0
33 <sub>5</sub> (channel boundary)			
Cu	883	4938	70
Pb	153	208	14
Zn	649	98	9
Mn	850	3168	56
Mo	11	1	1
Fe	52912	3084549	1756
Al	6901	968110	983
Ag	4	14	3
Cd	10	9	3



TABLE 3

PERCENT OF TOTAL SAMPLE RETAINED ON THE SEIVE

SMPL #	>590u <u>+1.92</u>	500u <u>+ .52</u>	250u <u>+ .75</u>	125u <u>+ .59</u>	62u <u>+ .77</u>	<62u <u>+ .40</u>
7	19.58	2.06	18.59	40.27	23.43	2.55
9	83.63	2.78	6.45	3.43	1.53	1.56
12	83.47	4.48	10.19	1.89	0.39	0.28
13	21.58	4.12	34.66	26.13	11.89	0.80
14	25.47	6.40	53.26	11.97	1.35	0.30
15	20.43	3.03	44.16	24.08	6.88	0.83
18	7.78	1.97	15.88	38.74	23.75	11.94
19	31.89	4.11	31.19	21.61	7.07	3.54
21	67.02	3.33	11.31	9.53	3.83	3.39
24	59.19	5.89	26.19	5.83	0.34	0.38
26	58.79	5.33	20.89	8.87	3.15	1.37
27	46.87	6.19	34.89	6.47	0.95	0.15
28	53.80	4.77	22.84	6.38	4.24	4.28
31	84.87	4.58	8.56	2.59	0.32	0.25
33	57.39	1.33	20.74	18.54	2.23	0.82

TABLE 4

MINERAL PHASES IN SILVER BOW CREEK SEDIMENT ACCORDING TO SIZE FRACTION

590u - 500u		<62u		COMMENTS
MINERALS	TREND DOWNSTREAM	MINERALS	TREND DOWNSTREAM	
Quartz	constant	Quartz	variable increase	less in <62u
Oligoclase	constant			absent in <62u
Orthoclase	variable decrease	Orthoclase	variable-absent	less in <62u
Muscovite	decrease	Muscovite	only in #18	
		Pyrite	variable-decrease	absent in 590-500u



TABLE 5

## VOLUMES OF SOLUTIONS USED AS LEACHANTS

Part of Leaching Run Flow Condition	VOLUMES (ml)									
	1				2				3	
	Low		High		Low		High		Low	High
	<u>FT</u>	<u>FO</u>	<u>FT</u>	<u>FO</u>	<u>FT</u>	<u>FO</u>	<u>FT</u>	<u>FO</u>	<u>FT</u>	<u>FO</u>
Silver Bow Creek	363	426	614	720						
Blacktail Creek	545	639	294	345						
1st Leachant					815	955	838	995		
Brown's Gulch					93	110	48	57		
2nd Leachant									469	550
German Gulch									695	815
									439	515
									213	250

TABLE 6

## RATES OF FLOW

<u>LOCATION</u>	<u>SITE #</u>	<u>RATE OF FLOW (cfs)</u>
Silver Bow Creek		
Blacktail Creek	12	
High Flow		22.36
Low Flow		7.14
Brown's Gulch	15	
High Flow		71.52
Low Flow		35.83
German's Gulch	18	
High Flow		59.50
Low Flow		19.55
Blacktail Creek	7	10.73
Brown's Gulch	16	4.11
German Gulch	19	18.28



TABLE 7

## SILVER BOW CREEK WATER TEMPERATURE

DATE MEASURED	TEMPERATURE ( $^{\circ}\text{C}$ )								Smpl. Site #
	12	13	14	15	18	22	27	33	
6/72	16	21	21	22	20	11	17	12	
7/72	16	16	16	18	19	14	17	22	
8/72	22			17	11		14	21	
11/72	5	6	6	7	2	1	3	2	
4/73	8	8	5	5	5	8	10	5	
6/73						10			
8/73	15				20				

\*Average Temperature =  $11.9^{\circ}\text{C}$

TABLE 8

## DIFFERENCES IN SEDIMENT COMPOSITION ALONG SILVER BOW CREEK

(13-33)	Cu	Pb	Zn	Mn	Mo	Fe	Al	Ag	Cd
Mid-channel	1736	80	18	-1006	-4	97511	1373	1	5
Avg.	2251	129	40	-346	3	104729	-265	3.2	1
(13-32)									
Mid-channel	290	132	57	-30	9	95912	-2872	4	7
Avg.	98	159	22	-102	10	100610	-2495	4.6	4.4
(32-33)									
Mid-channel	-98	-30	17	-244	-7	4119	2230	-1.4	-3.4
Avg.	-290	-50	-39	-976	-13	15990	4245	-3	-2

TABLE 9

## AVERAGE OF THE MEAN CONCENTRATIONS OF EACH SITE ACROSS THE CHANNEL

Sample Site	Concentration (mg/l)								
	Cu	Pb	Zn	Mn	Mo	Fe	Al	Ag	Cd
13	3012	283	546	597	15	146940	5979	6.4	8.4
33	761	154	614	943	12	42211	6244	3.2	7.4
32	663	124	631	699	5	46330	8474	1.8	4



TABLE 10  
CATION CONCENTRATIONS IN THE TRIBUTARIES

	Concentrations (mg/l)					
	<u>Fe</u>	<u>Cu</u>	<u>Mn</u>	<u>Zn</u>	<u>Al</u>	<u>Si</u>
Blacktail Creek	0.1	<0.02	0.24	0.02	<0.5	26.9
	0.45	0.02	0.65	0.09		32.8
Brown's Gulch	0.29	<0.02	0.05	<0.01	<0.5	34.0
		0.02	0.12	0.09	0.5	45.0
German Gulch	<0.02	<0.02	<0.01	0.01	<0.5	15.9
	0.24	0.02	0.06	0.16		20.0



FIGURE 1

## LEACHING VESSELS

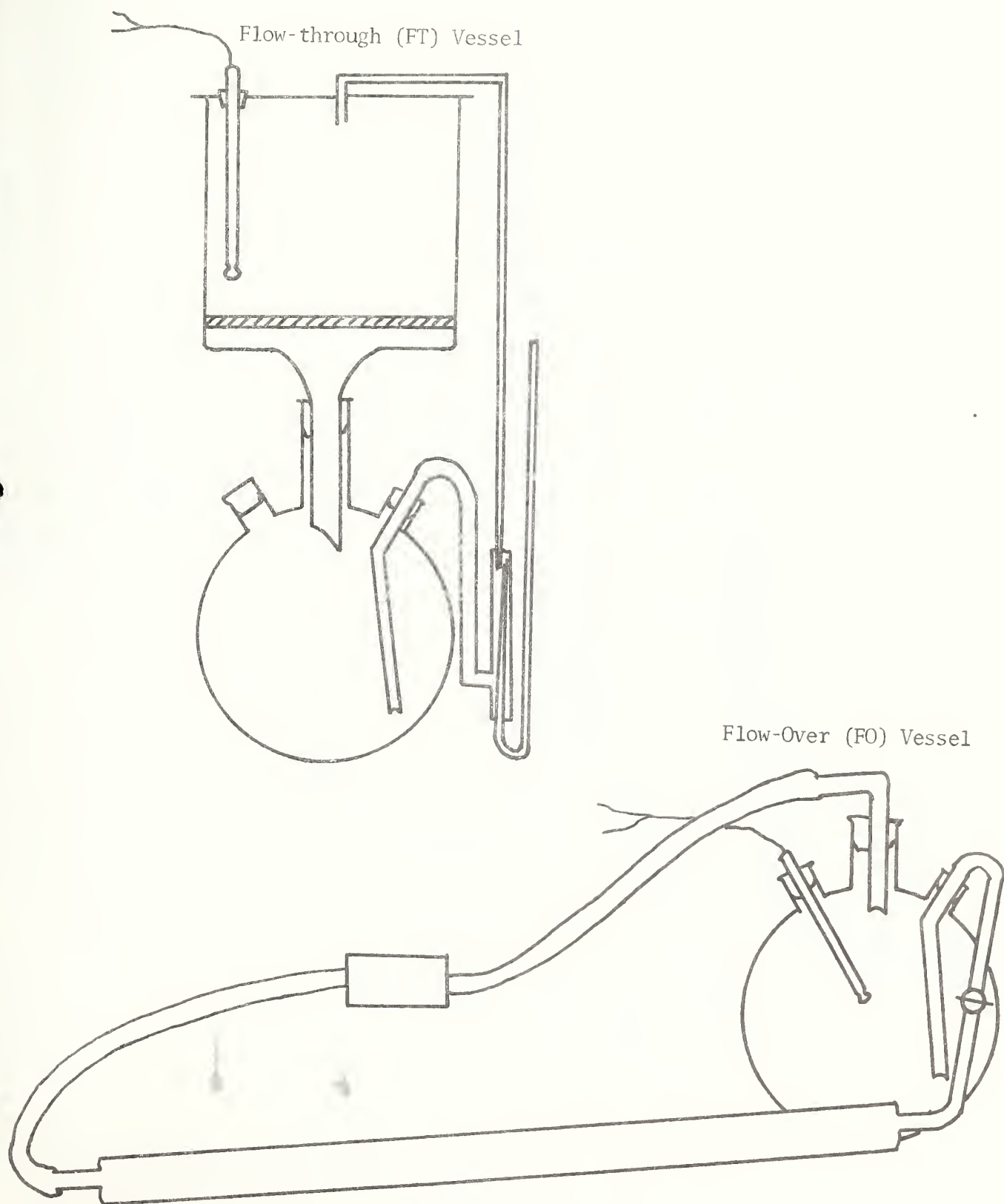
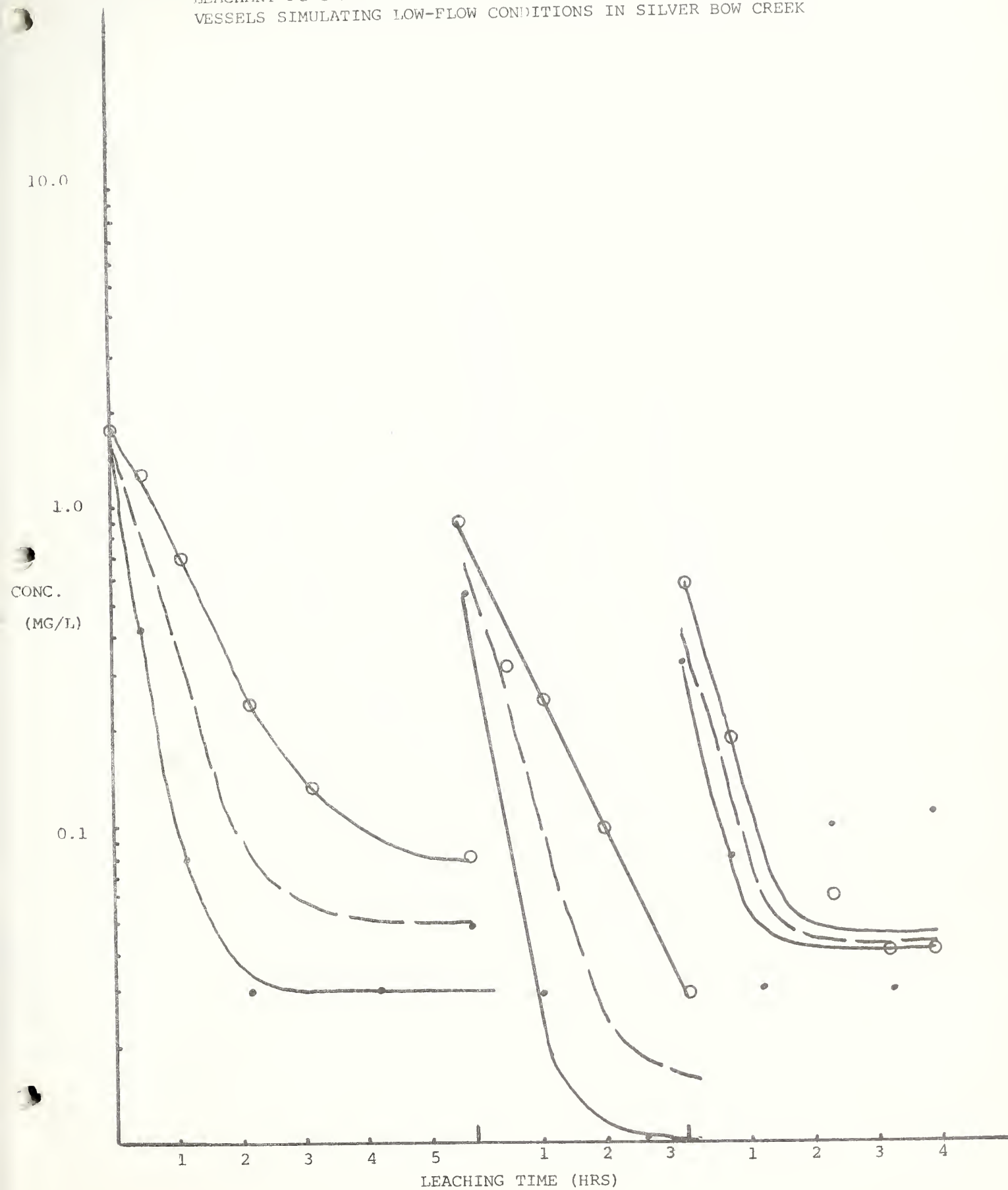




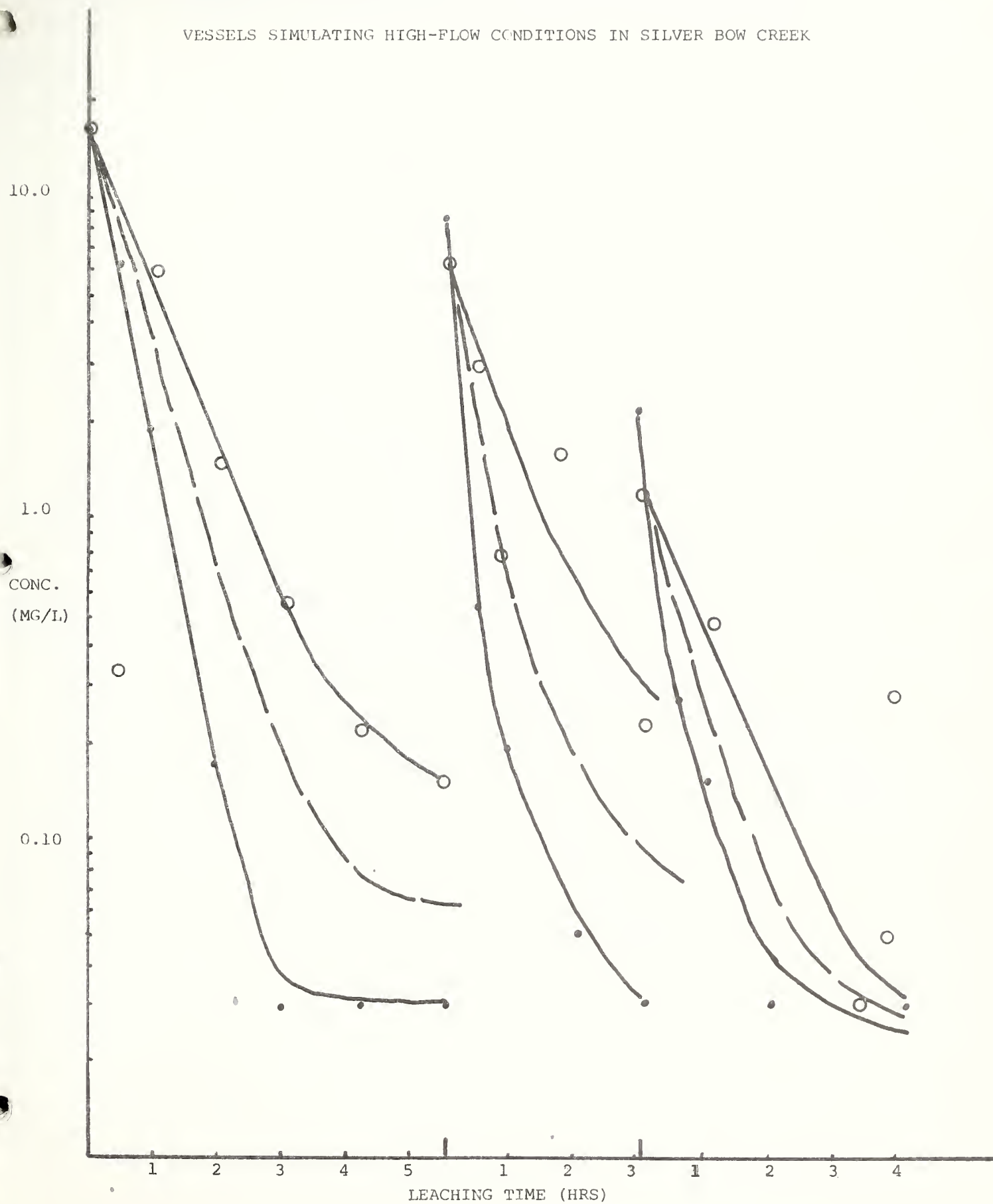
FIGURE 2

LEACHANT Fe CONCENTRATION vs LEACHING TIME FOR FLOW-THROUGH  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK



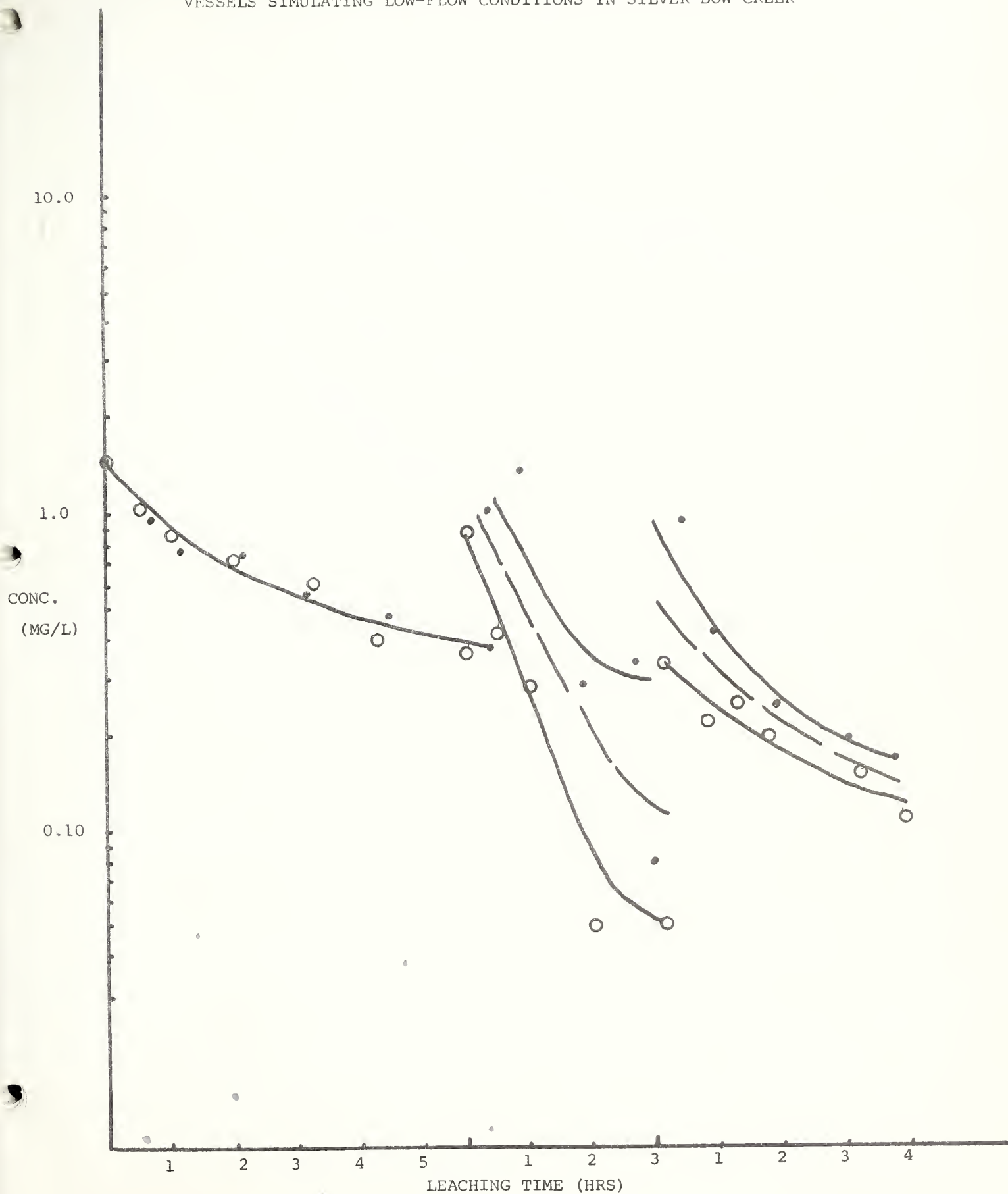


LEACHANT Fe CONCENTRATION vs LEACHING TIME FOR FLOW THROUGH  
VESSELS SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK



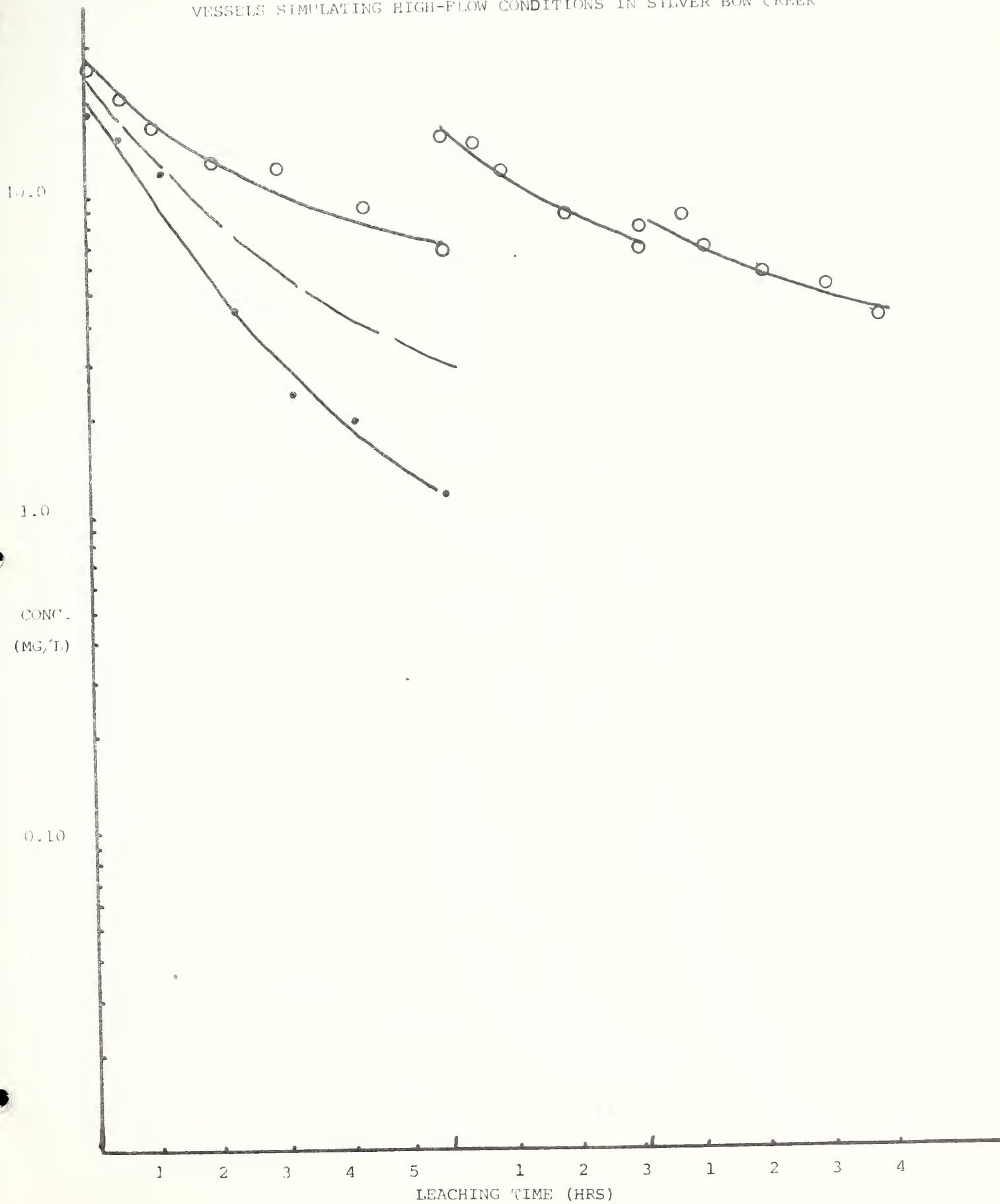


LEACHANT Fe CONCENTRATION vs LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK



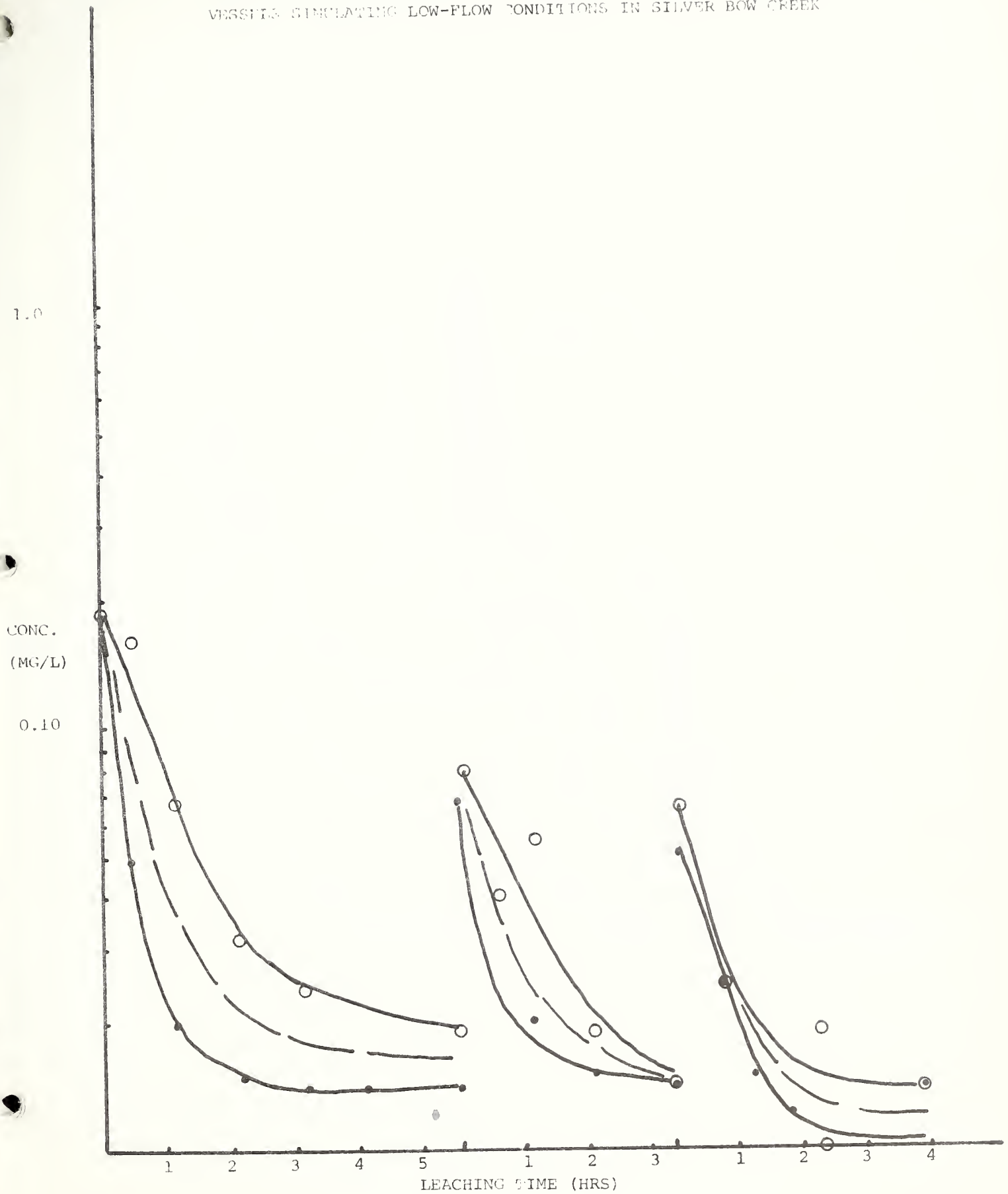


LEACHANT Fe CONCENTRATION vs LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK





LEACHANT Cu CONCENTRATION vs LEACHING TIME FOR FLOW-THROUGH  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK





LEACHANT Cu CONCENTRATION VS. LEACHING TIME FOR FLOW-THROUGH  
VESSEL SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK

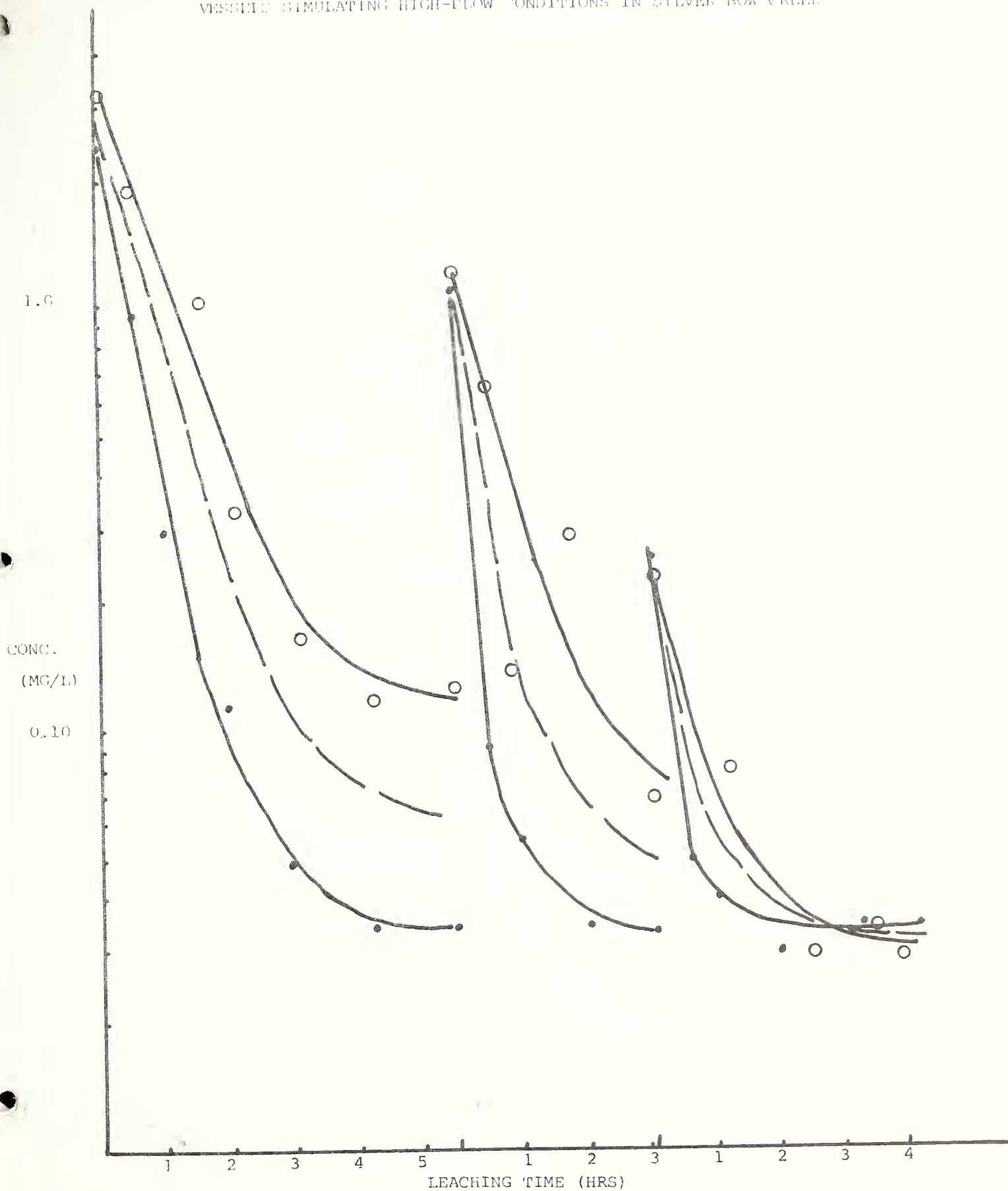
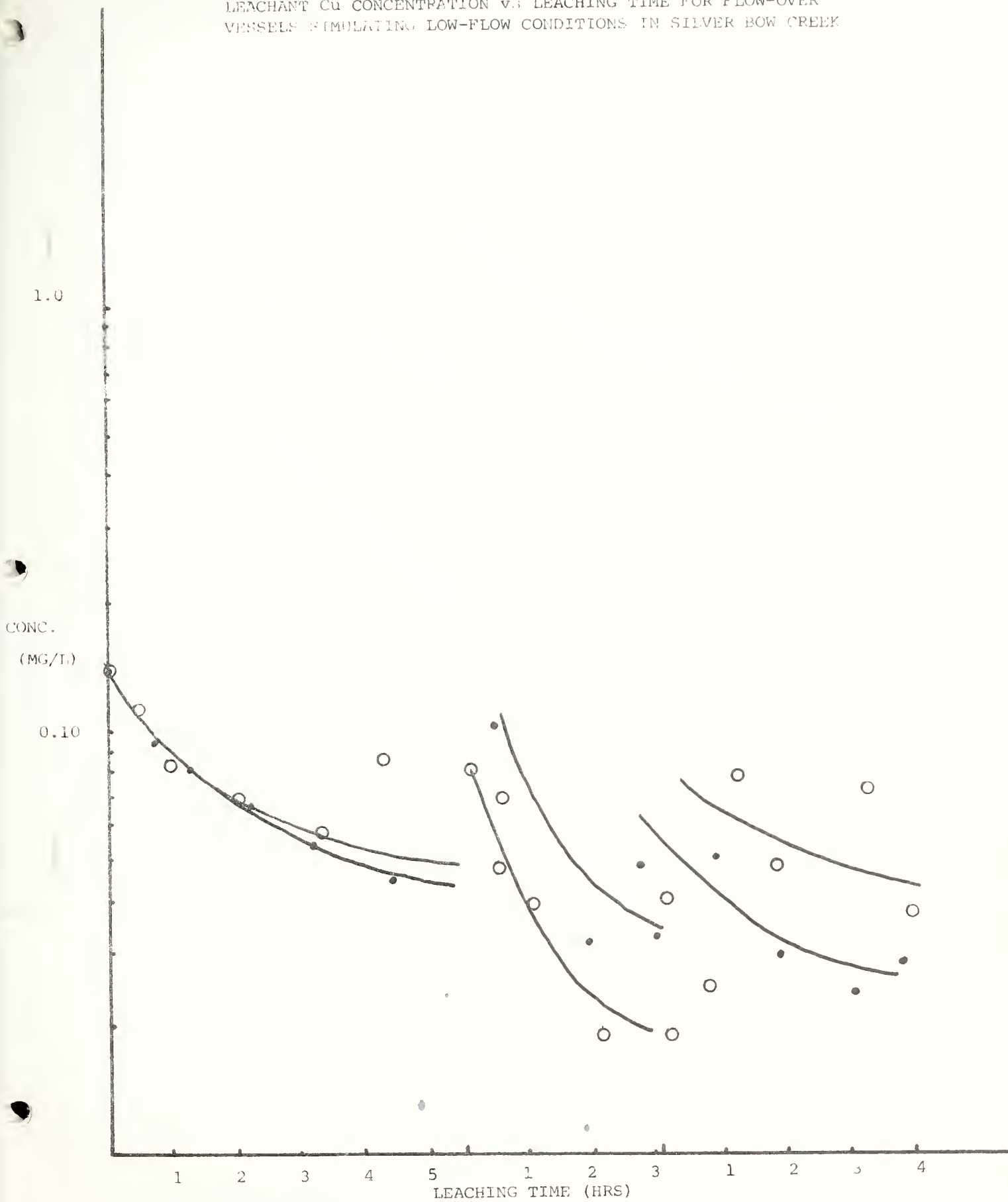




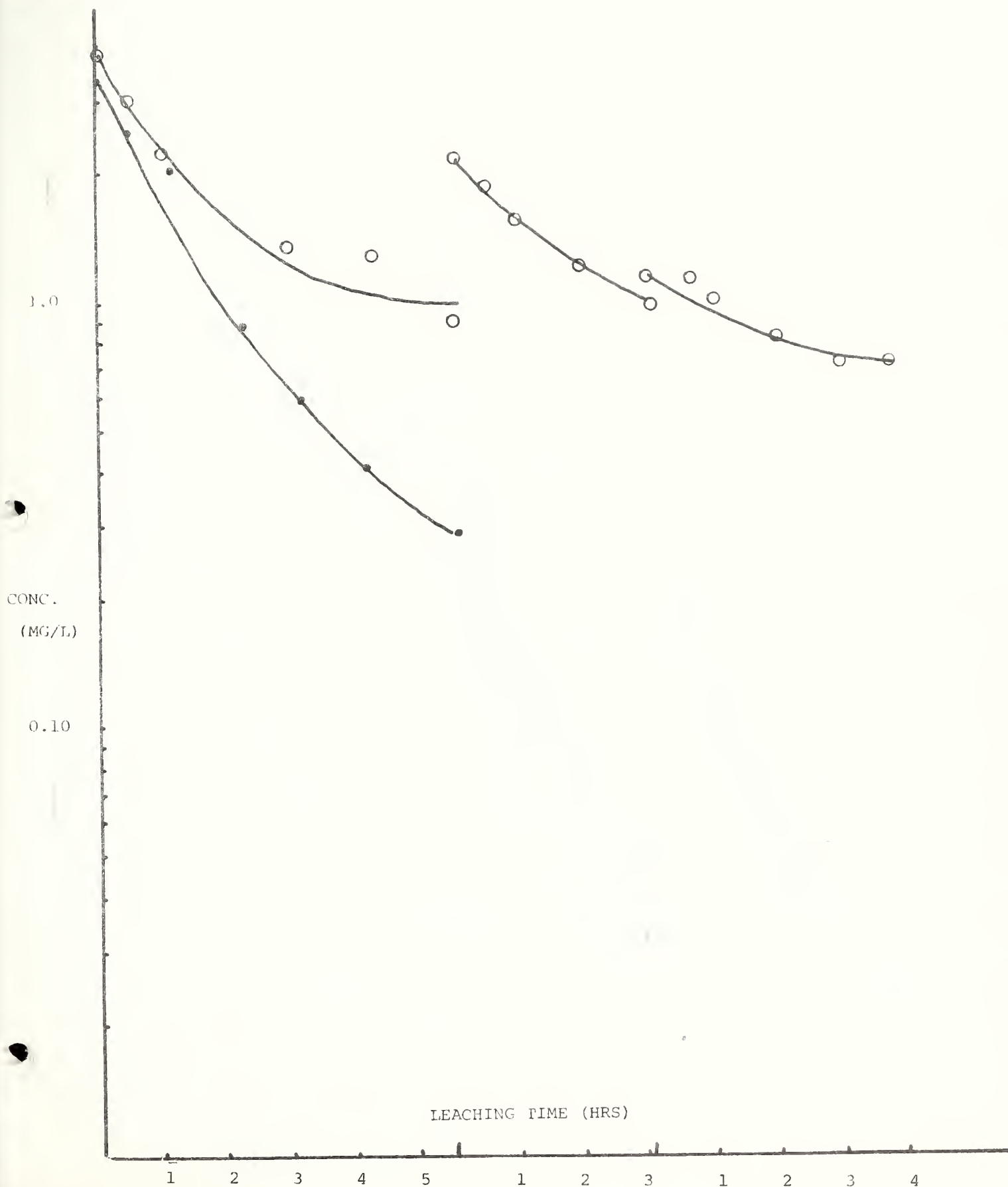
FIGURE 8

LEACHANT CU CONCENTRATION v.s. LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK





LEACHANT CU CONCENTRATION vs. LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK





LEACHANT  $\text{Mn}$  CONCENTRATION VS LEACHING TIME FOR FLOW-THROUGH  
VESSELS EMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK

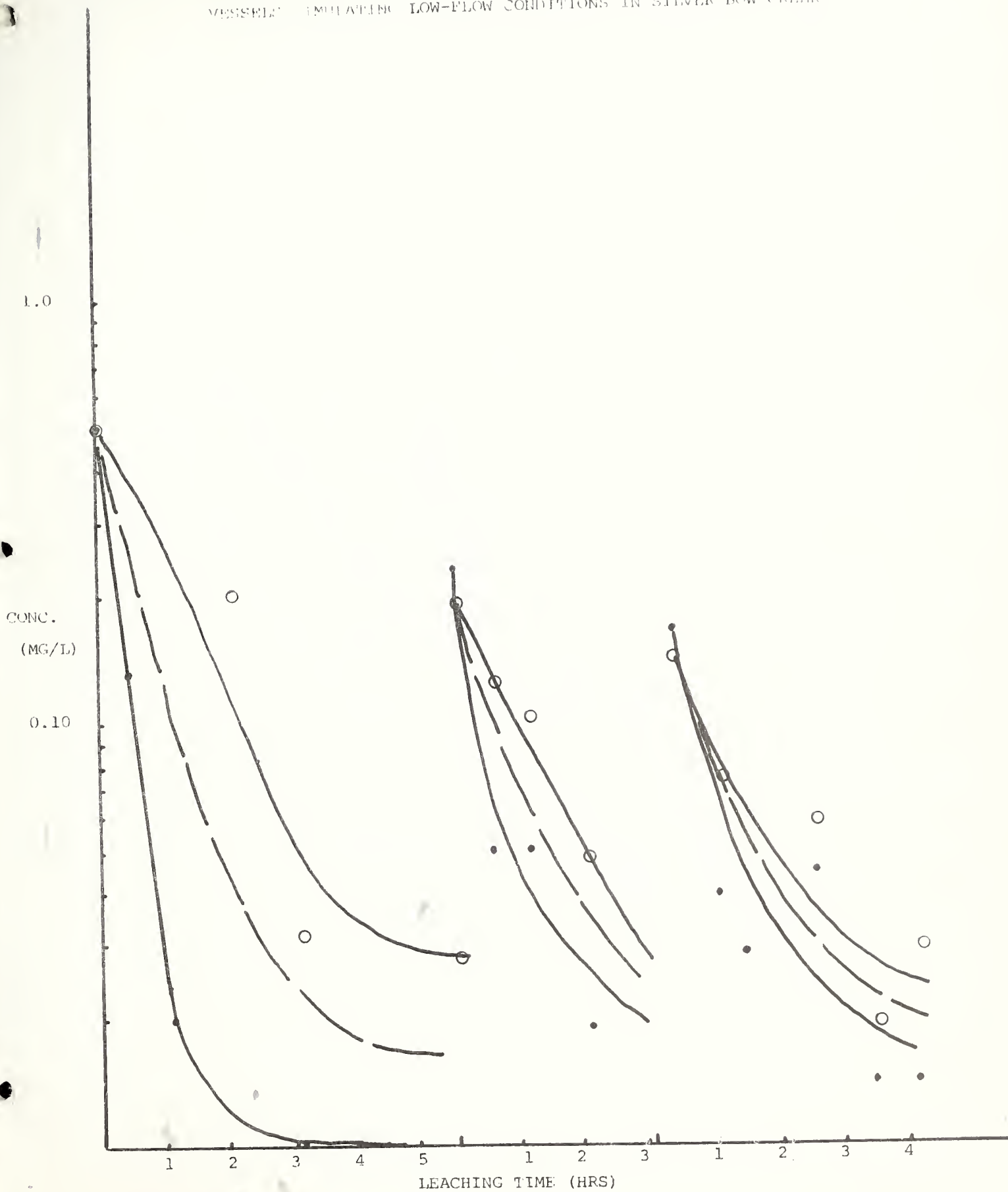
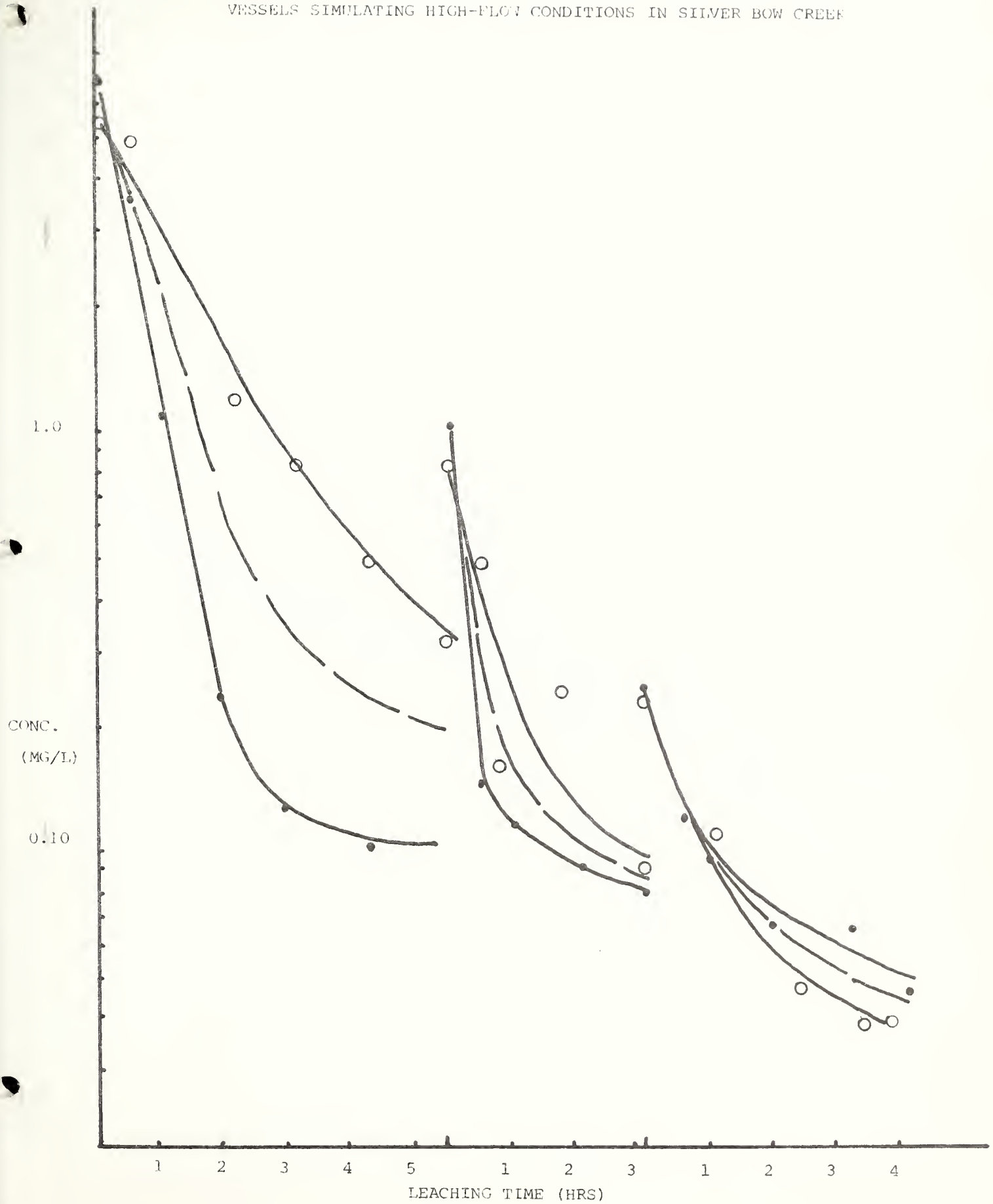




FIGURE 11

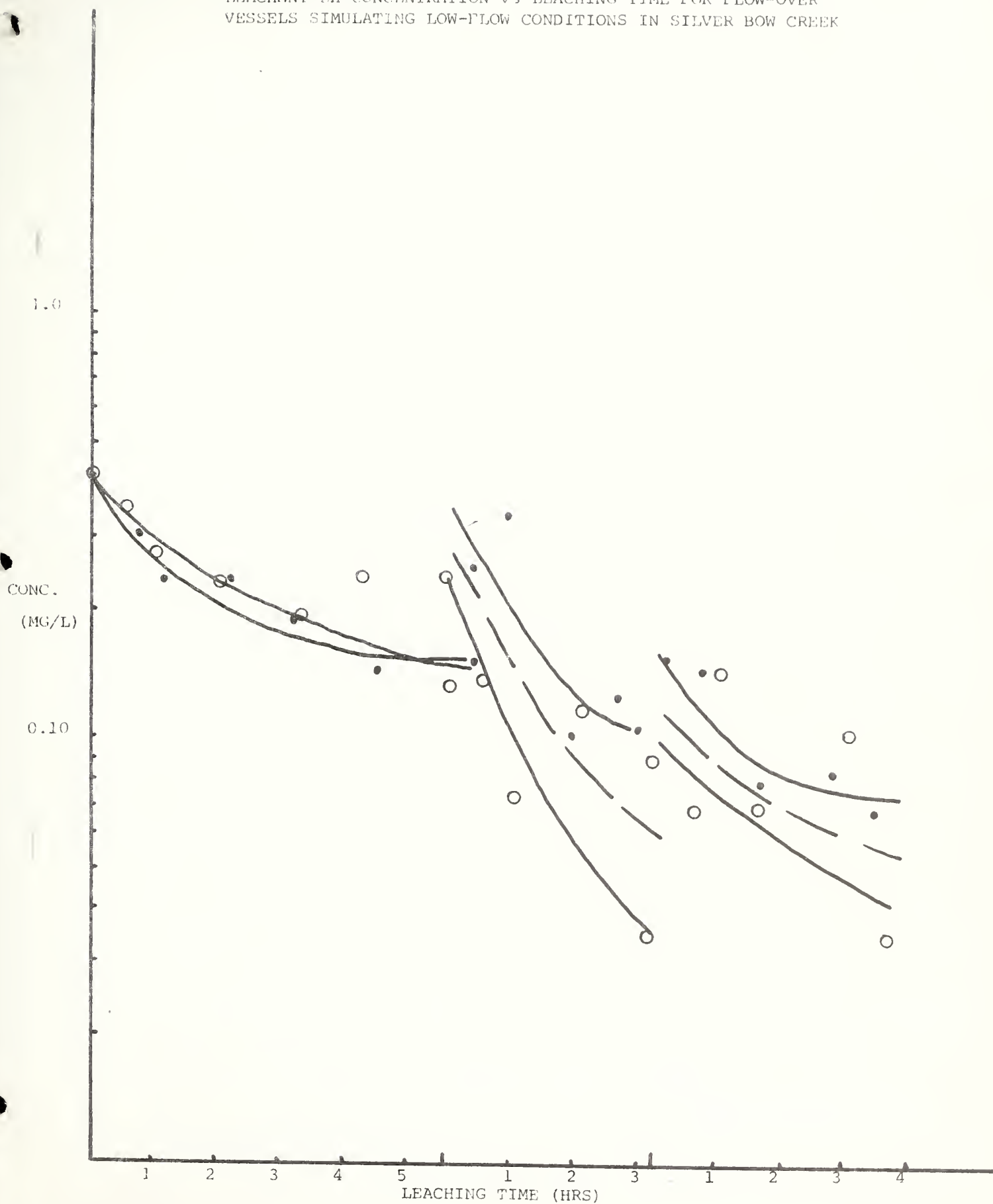
10A

LEACHANT Zn CONCENTRATION v. LEACHING TIME FOR FLOW-THROUGH  
VESSELS SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK





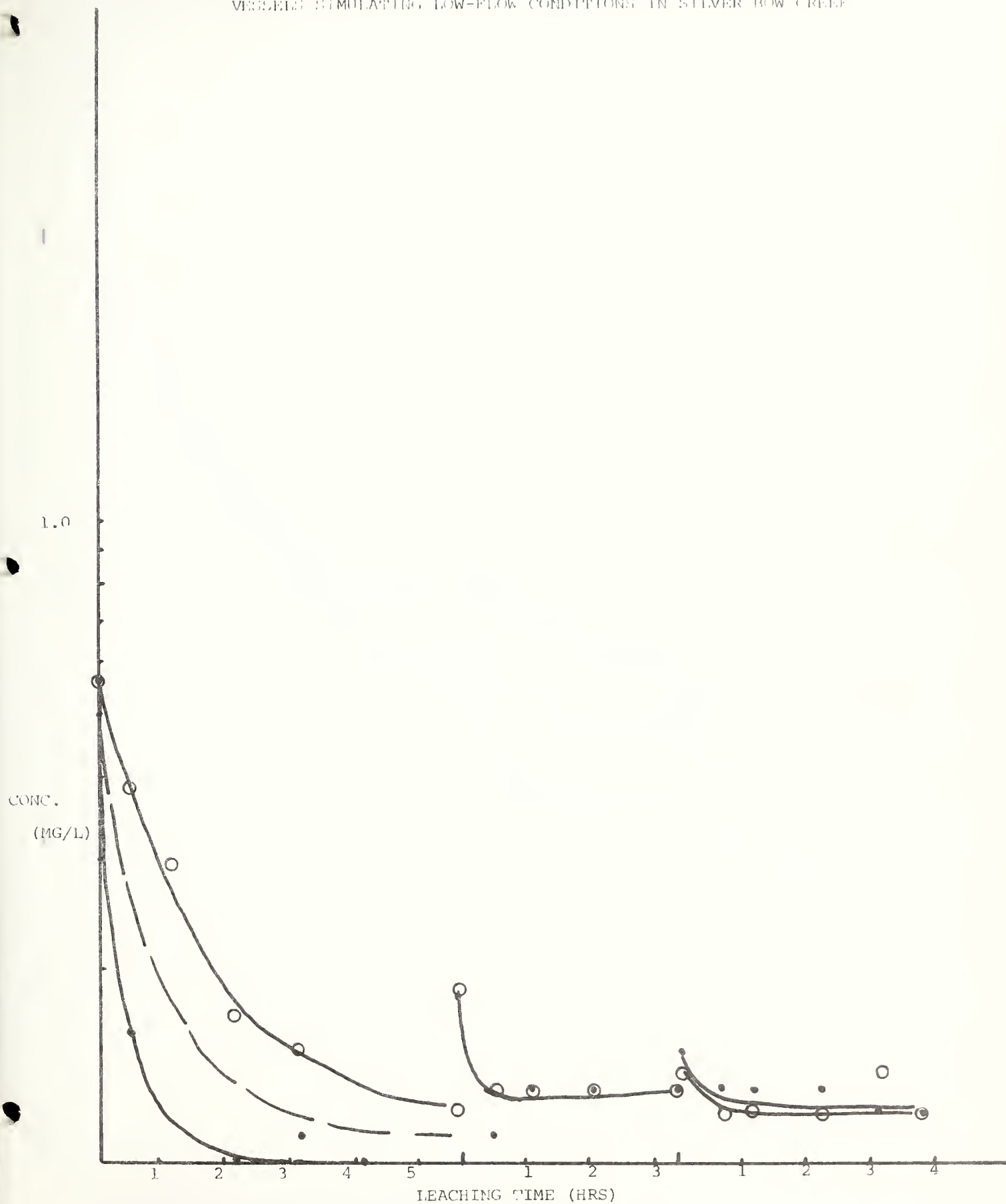
LEACHANT Zn CONCENTRATION vs LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK



ANALYSIS OF VARIATION IN  
TEMPERATURE, 1961-62



LEACHANT Mn CONCENTRATION VS LEACHING TIME FOR FLOW-THROUGH  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK





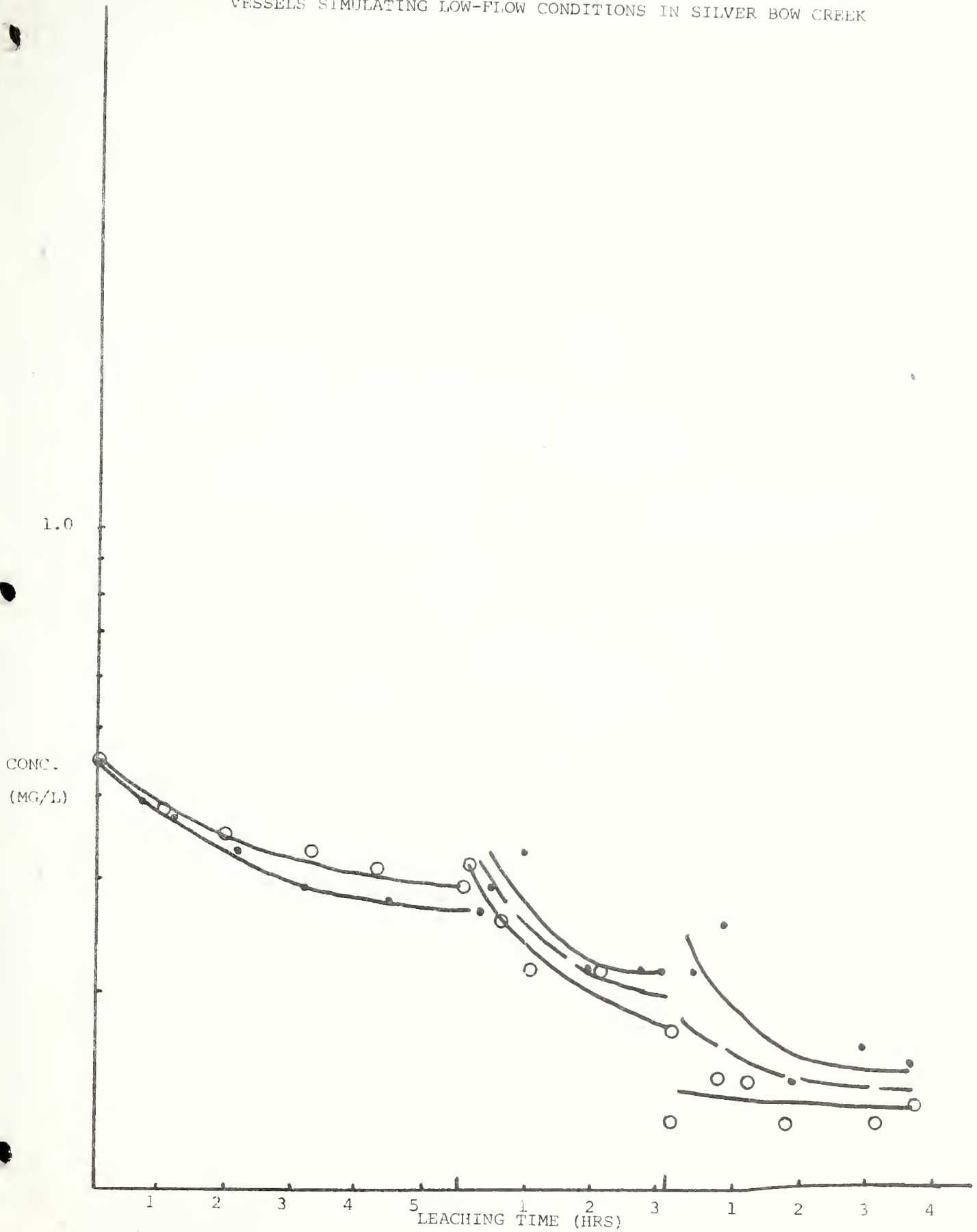
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CONC.  
(MG/L)

LEACHING TIME (HRS)

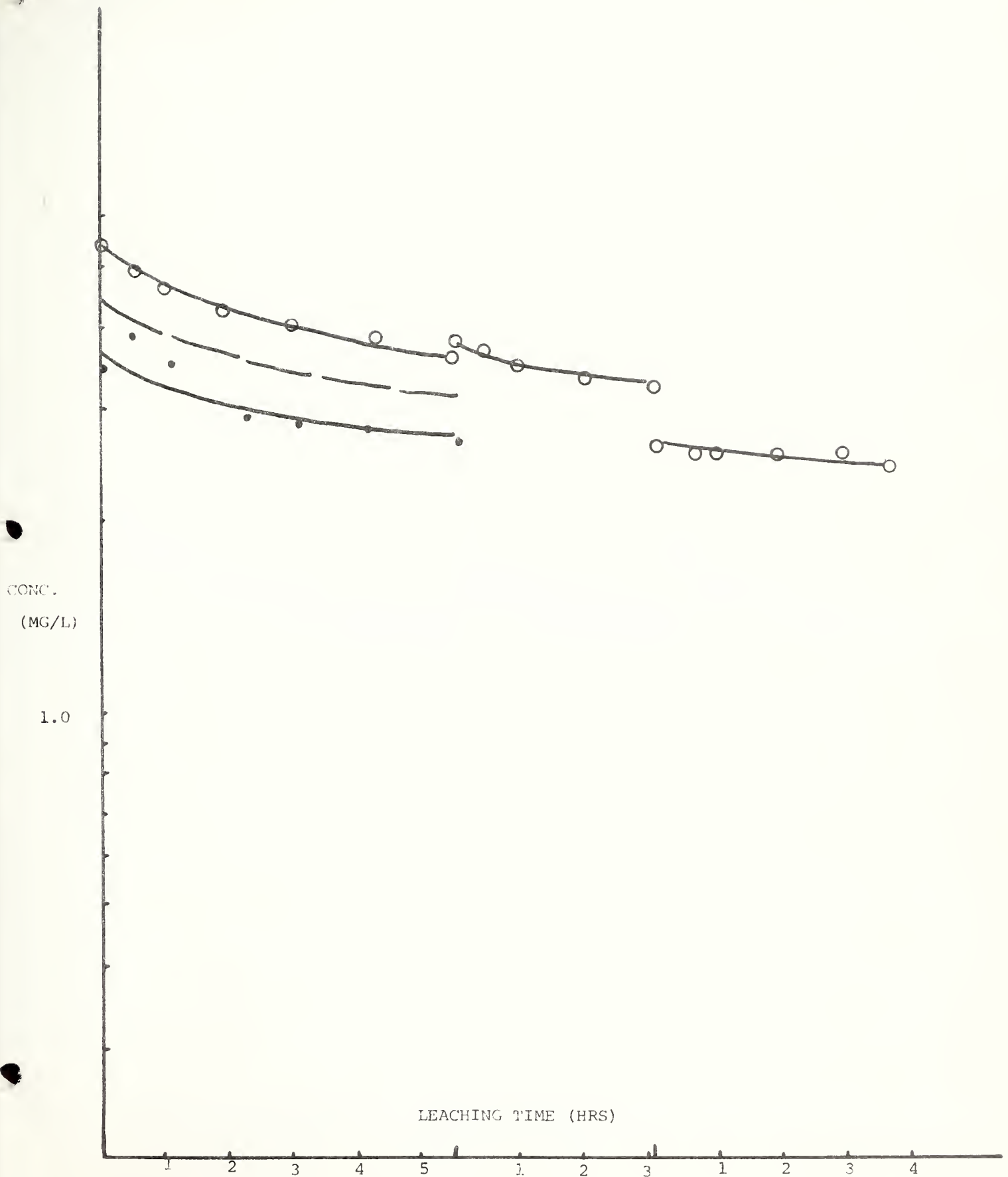


LEACHANT Mn CONCENTRATION v. LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK



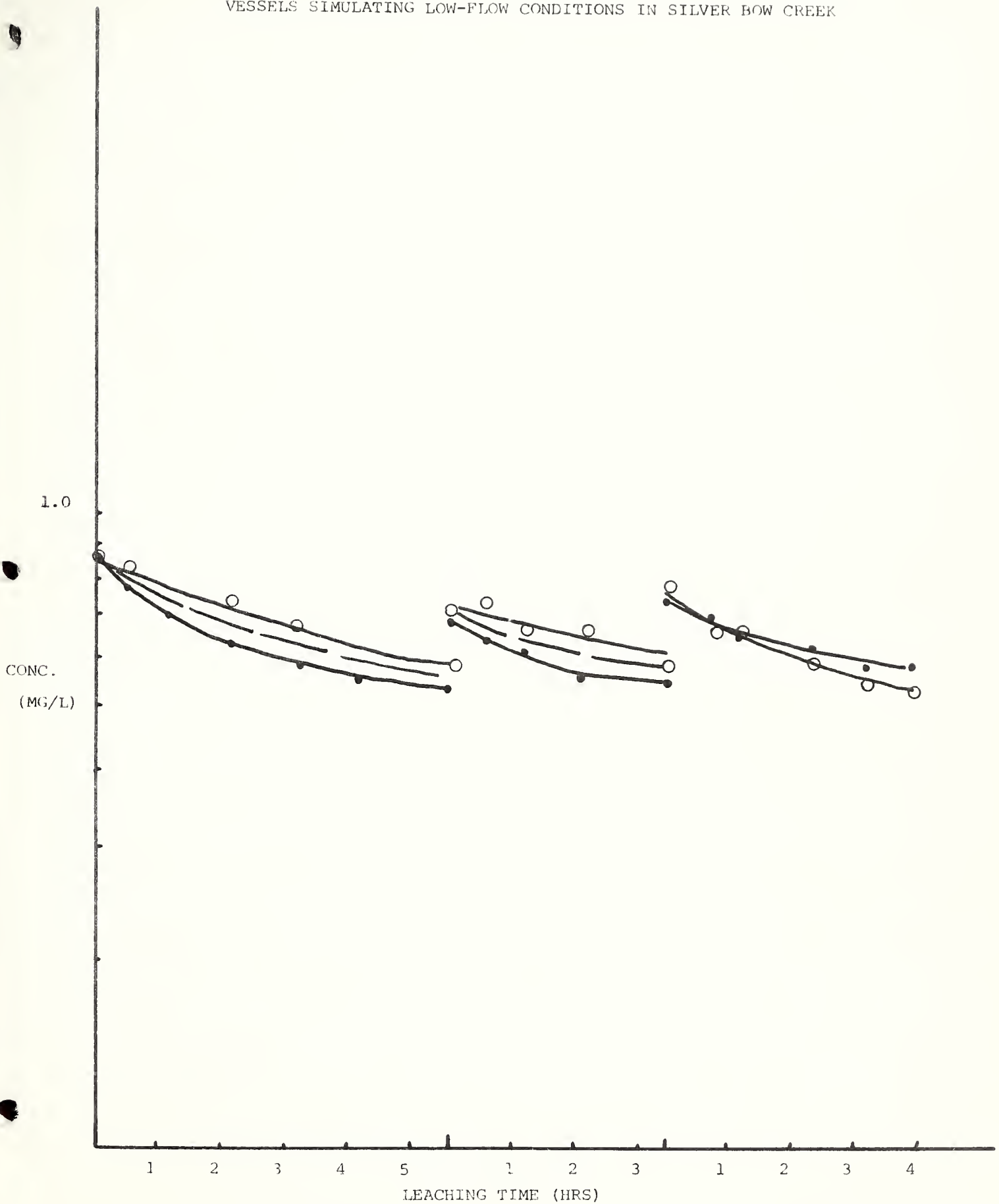


LEACHANT Mn CONCENTRATION v. LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK



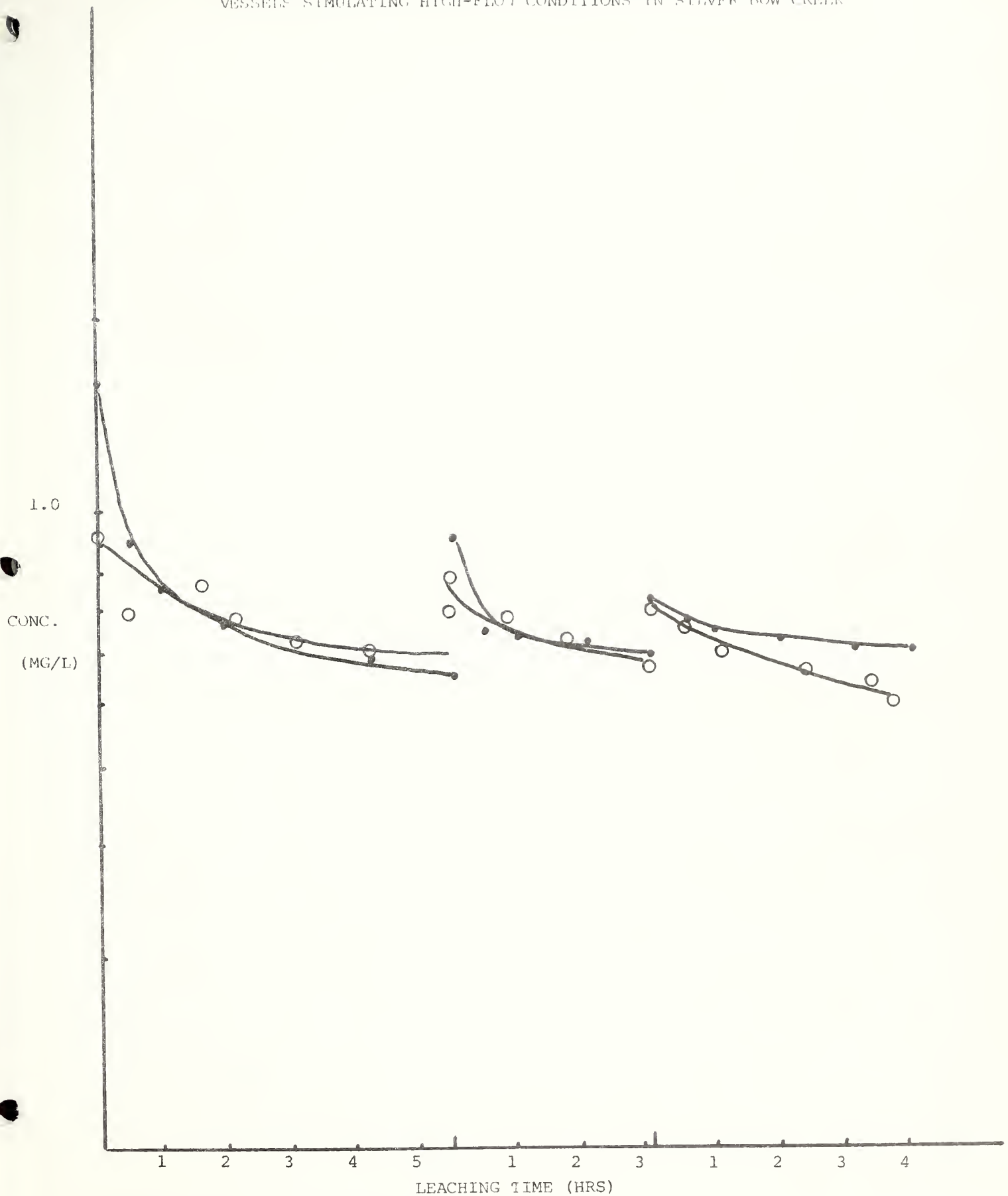


LEACHANT Si CONCENTRATION vs LEACHING TIME FOR FLOW-THROUGH  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK



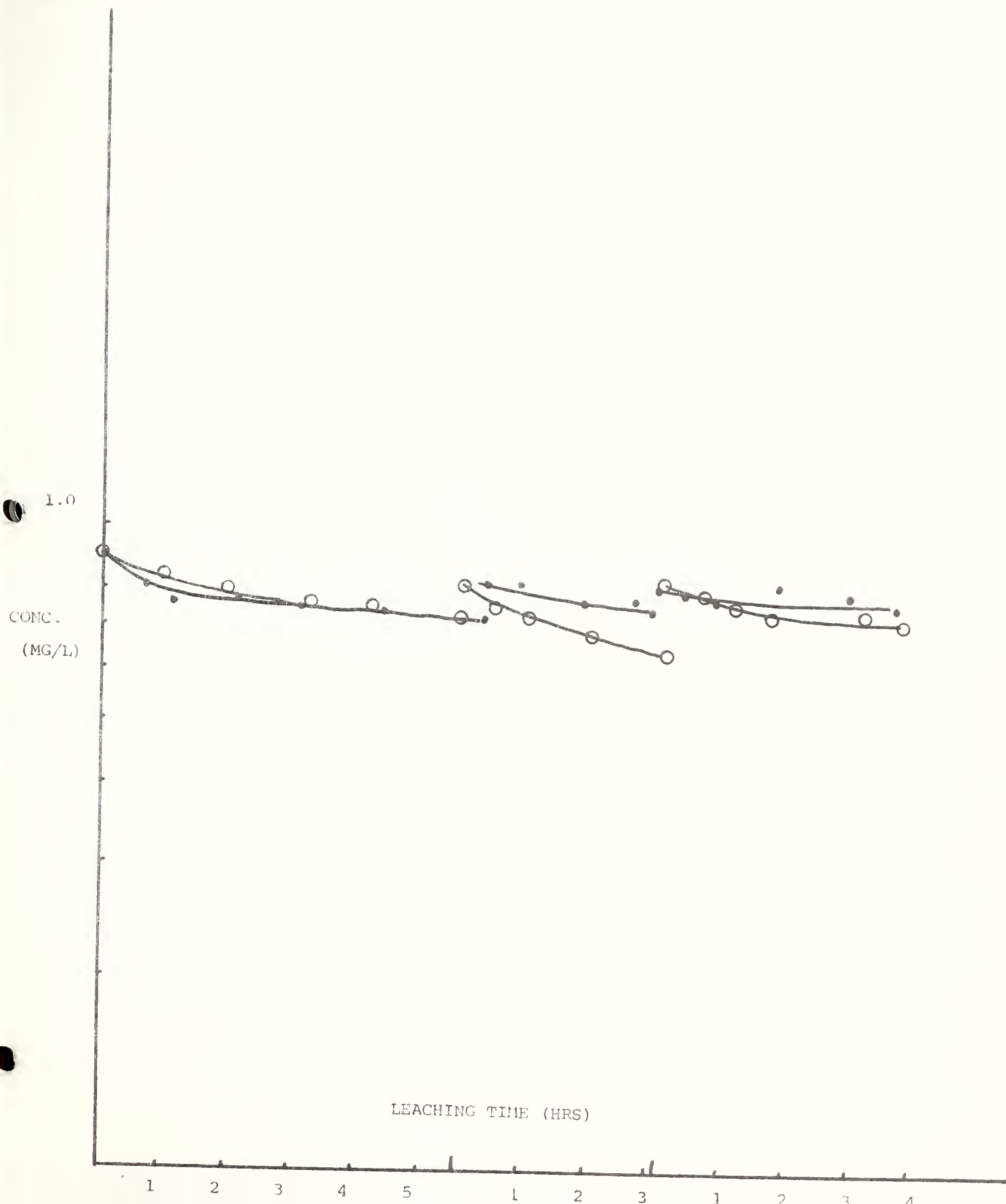


LEACHANT Si CONCENTRATION v; LEACHING TIME FOR FLOW-THROUGH  
VESSELS SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK



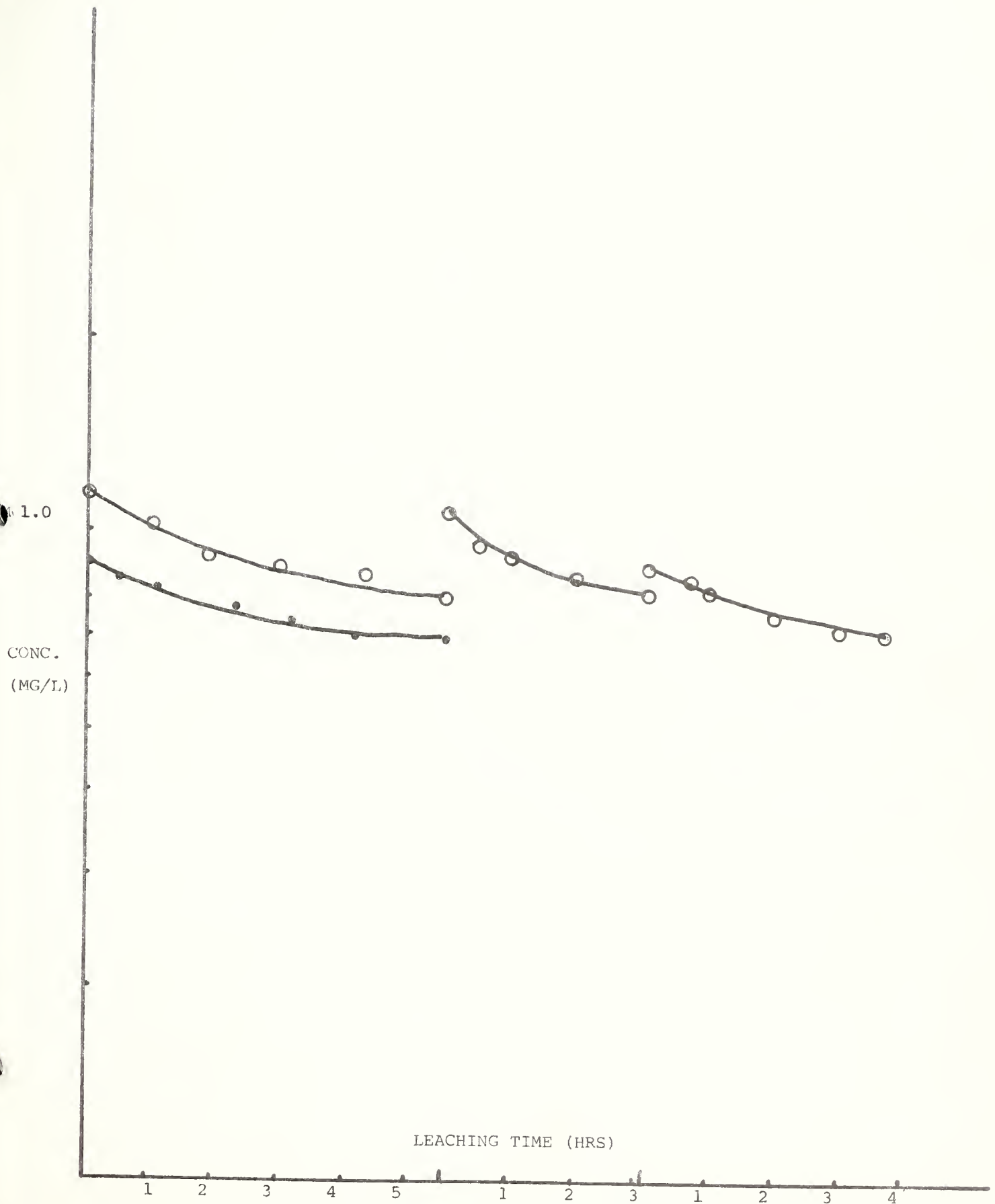


LEACHANT S<sub>1</sub> CONCENTRATION vs LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK



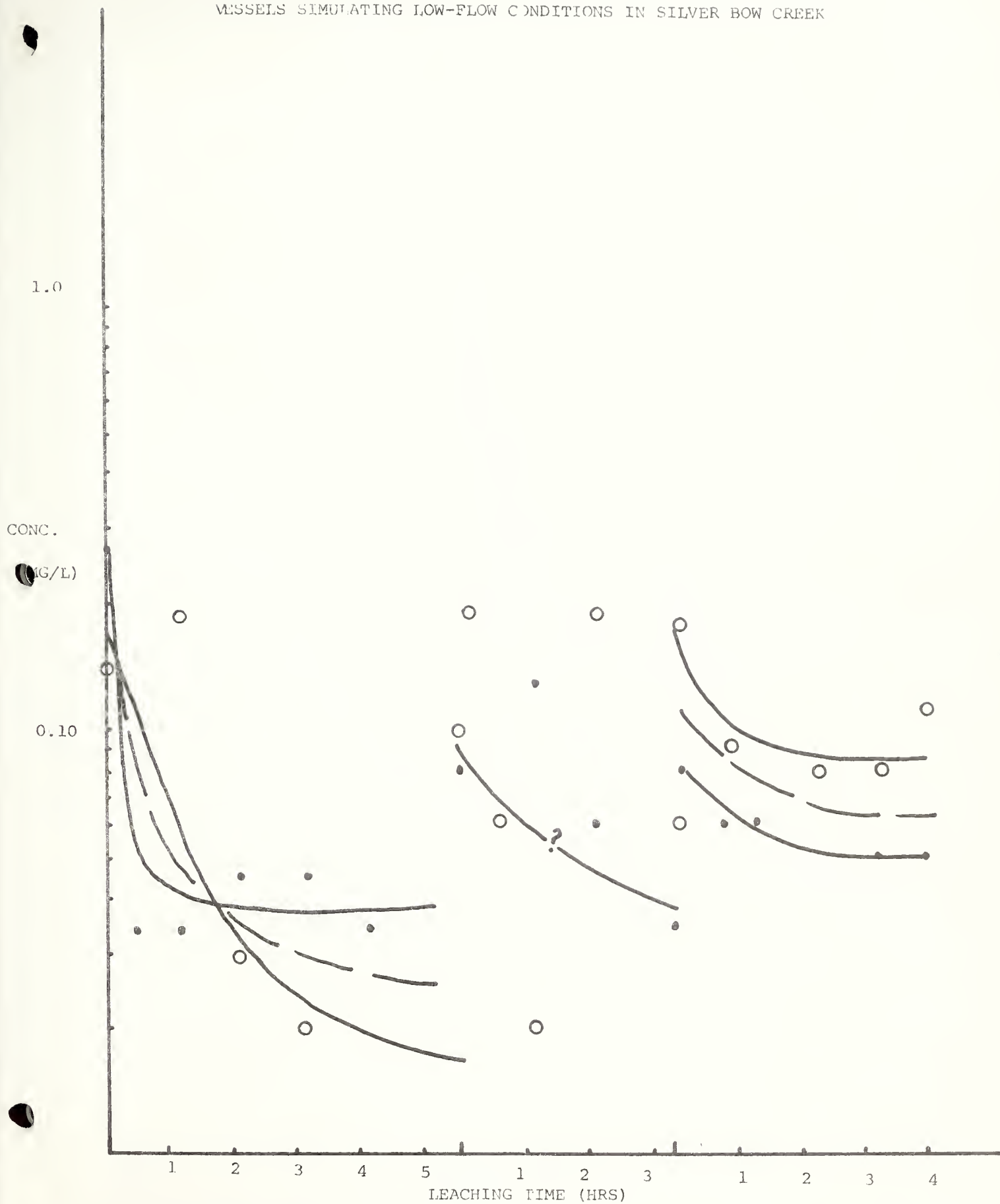


LEACHANT Si CONCENTRATION vs LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK





LEACHANT Al CONCENTRATION vs LEACHING TIME FOR FLOW-THROUGH  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK



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1.0

CONC.  
(MG/L)

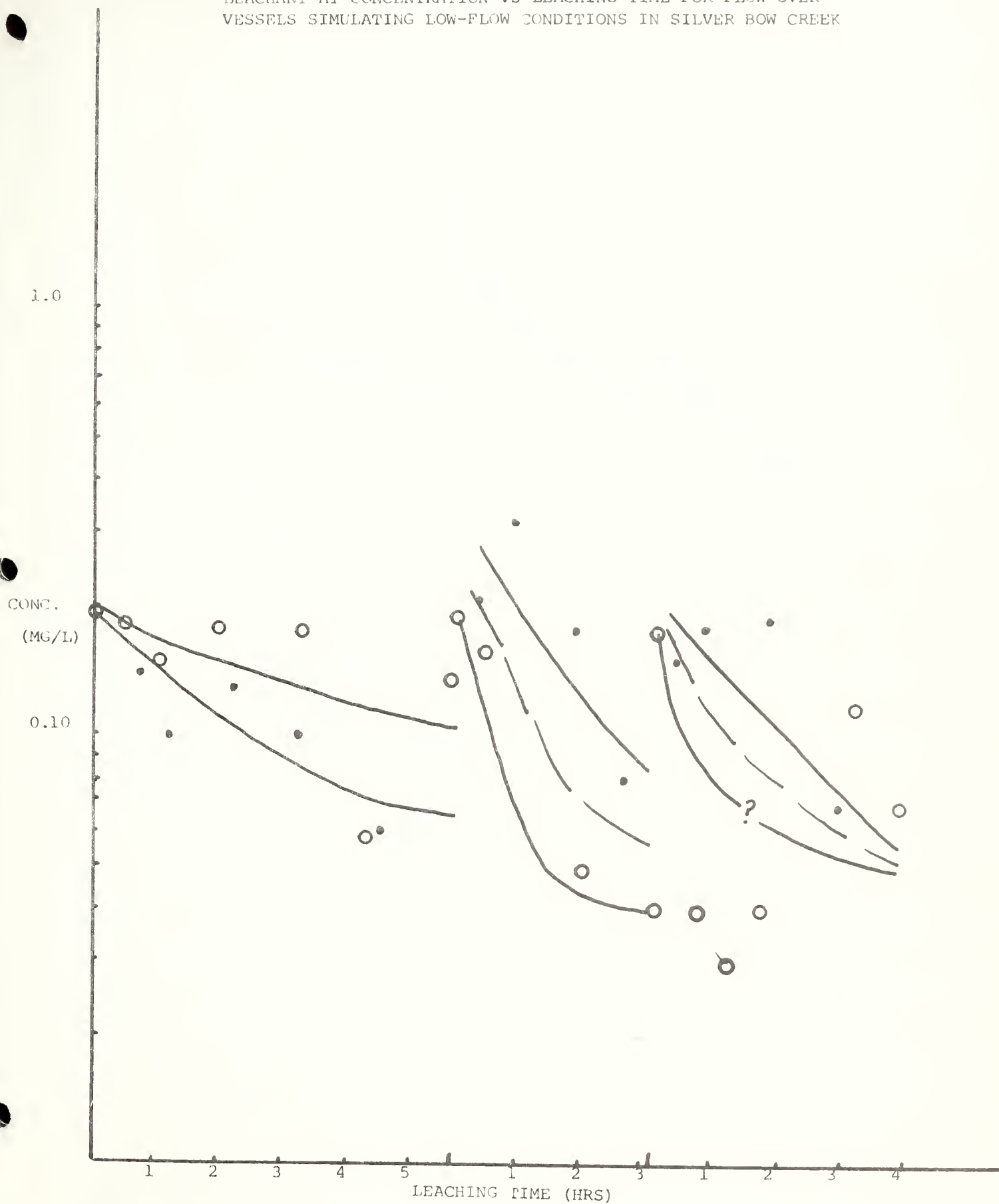
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LEACHING TIME (HRS)

1 2 3 4 5 1 2 3 1 2 3 4

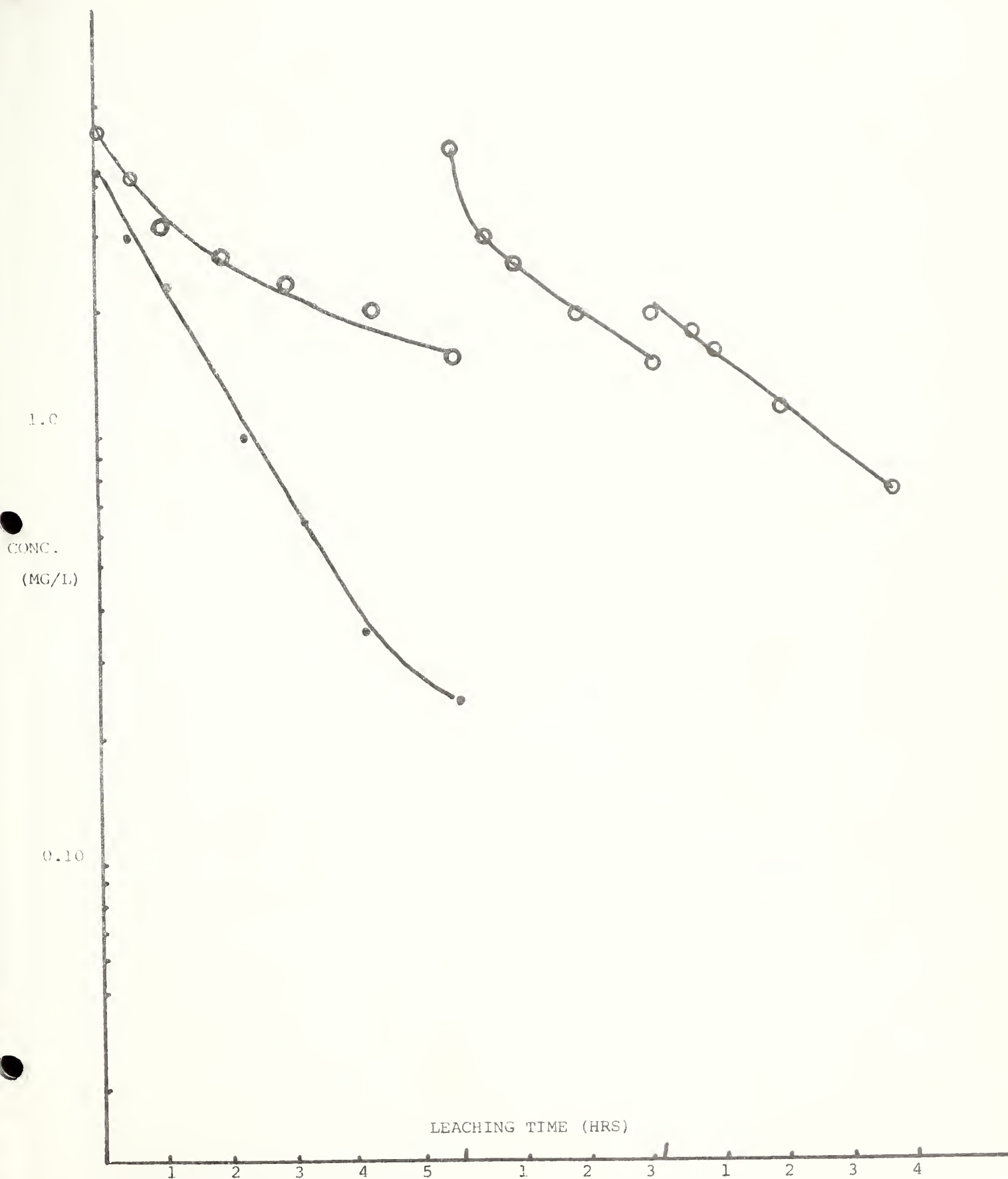


LEACHANT Al CONCENTRATION vs LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING LOW-FLOW CONDITIONS IN SILVER BOW CREEK



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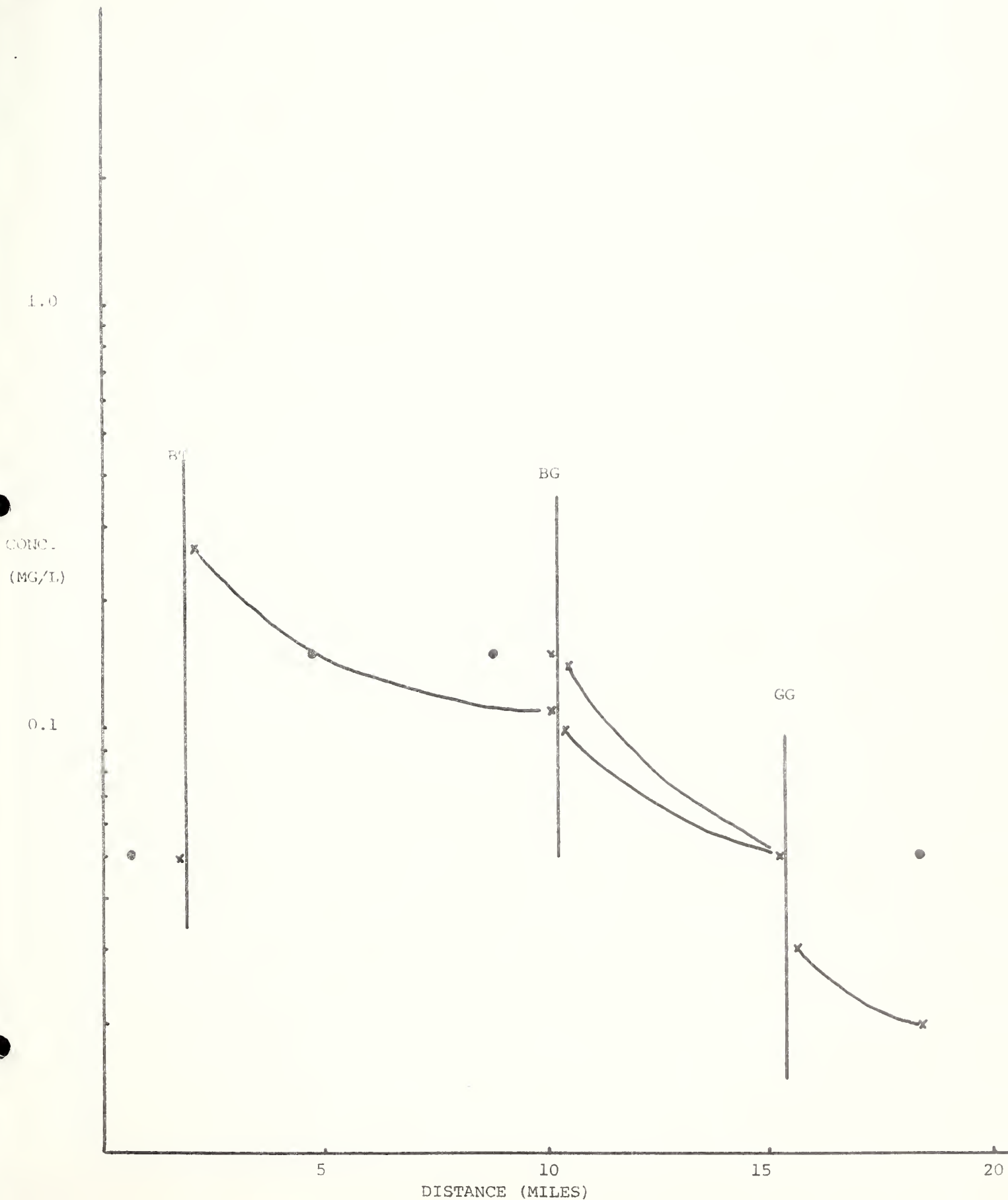
LEACHANT Al CONCENTRATION vs LEACHING TIME FOR FLOW-OVER  
VESSELS SIMULATING HIGH-FLOW CONDITIONS IN SILVER BOW CREEK



RELATIONSHIP BETWEEN  $\log K_{eq}$  AND  $\log K_{eq}^0$  FOR  
 VARIOUS POLYMERIZATION SYSTEMS



CONCENTRATION (MODEL & AUGUST 1, 1973 STREAM DATA) IN SILVER  
BOW CREEK WATER FROM IT'S INTERSECTIONS WITH BLACKTAIL CREEK (BT),  
BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS

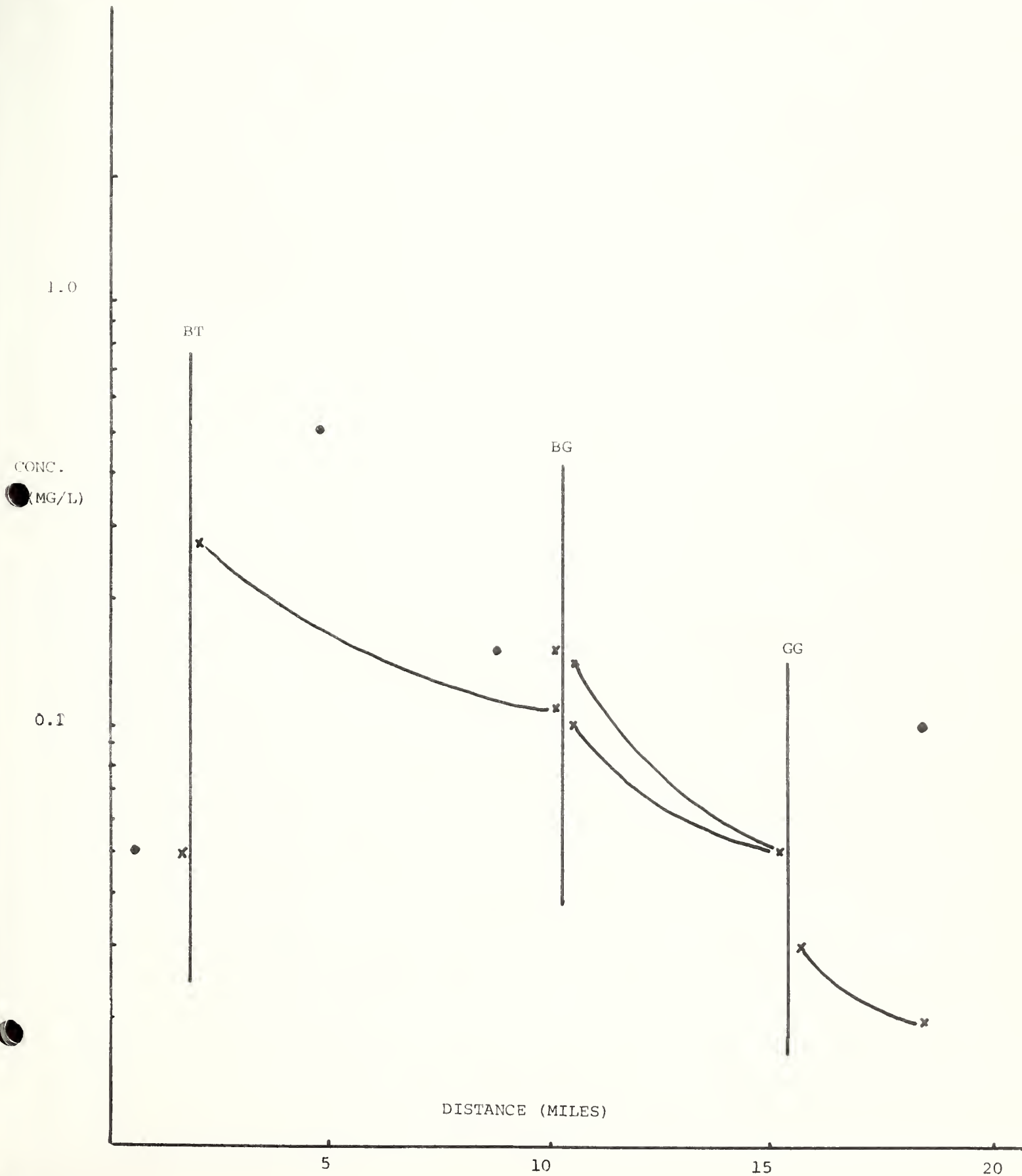


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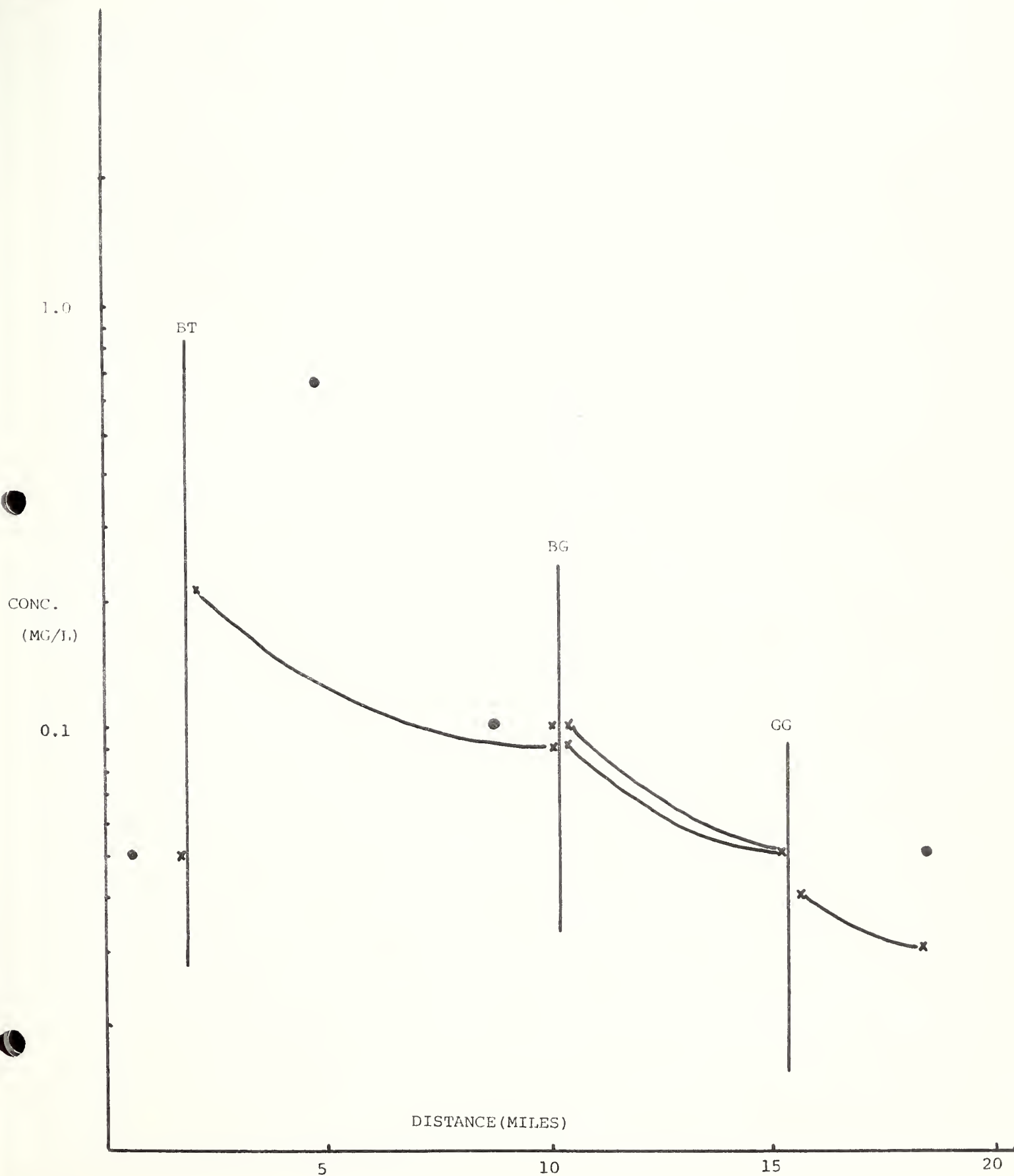
IT IS NOT TO BE USED AS A BASIS FOR ANY OTHER ACTION

Fe CONCENTRATION (MODEL & AUGUST 7, 1973 STREAM DATA) IN SILVER BOW CREEK WATER FROM IT'S INTERSECTIONS WITH BLACKTAIL CREEK (BT), BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS





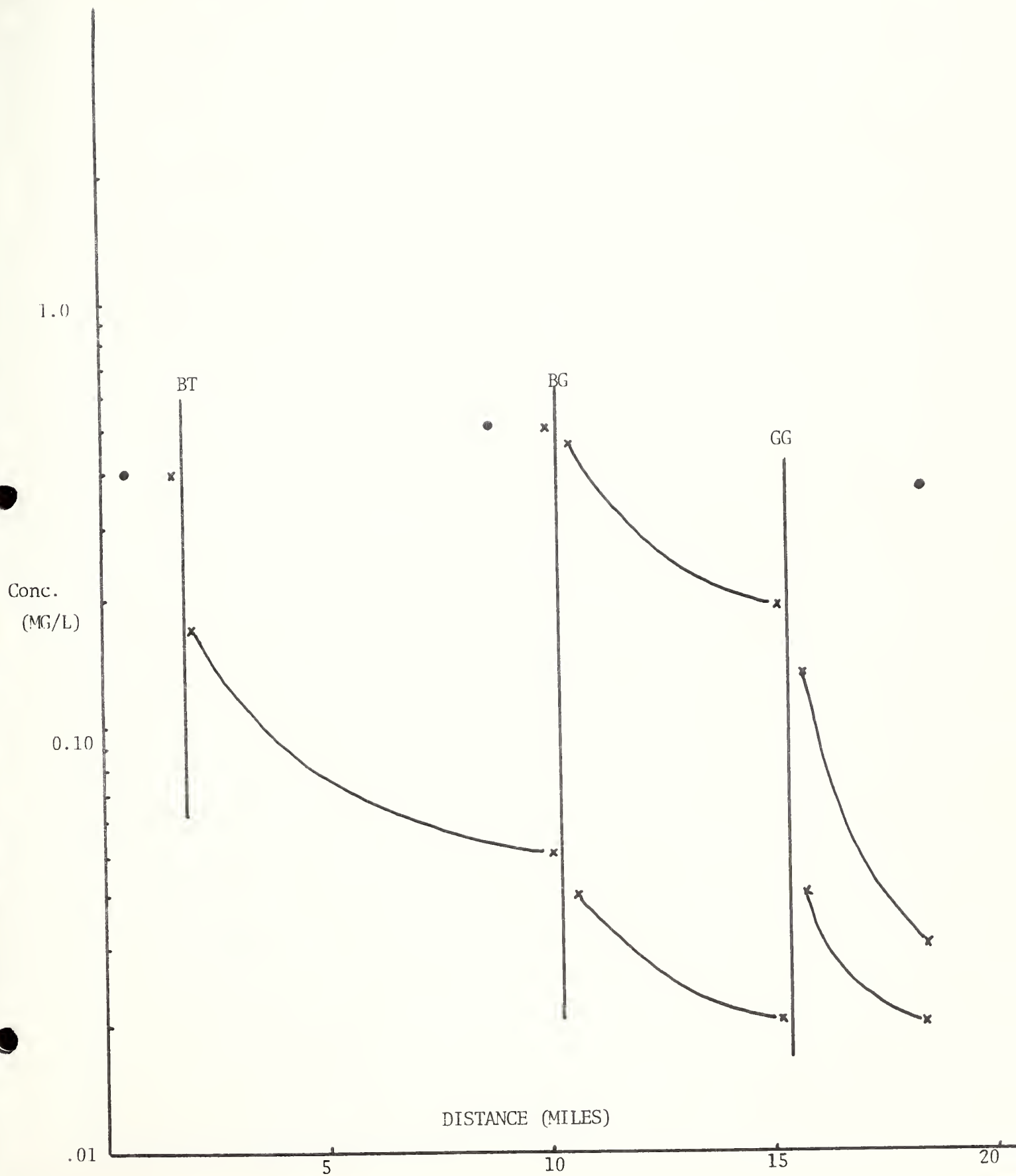
PG CONCENTRATION (MODEL & AUGUST 14, 1973 STREAM DATA) IN SILVER  
BOW CREEK WATER FROM IT'S INTERSECTION WITH BLACKTAIL CREEK (BT),  
BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS



1. The following table shows the results of the tests made with the apparatus described in the preceding pages. The values given are the average of three readings.

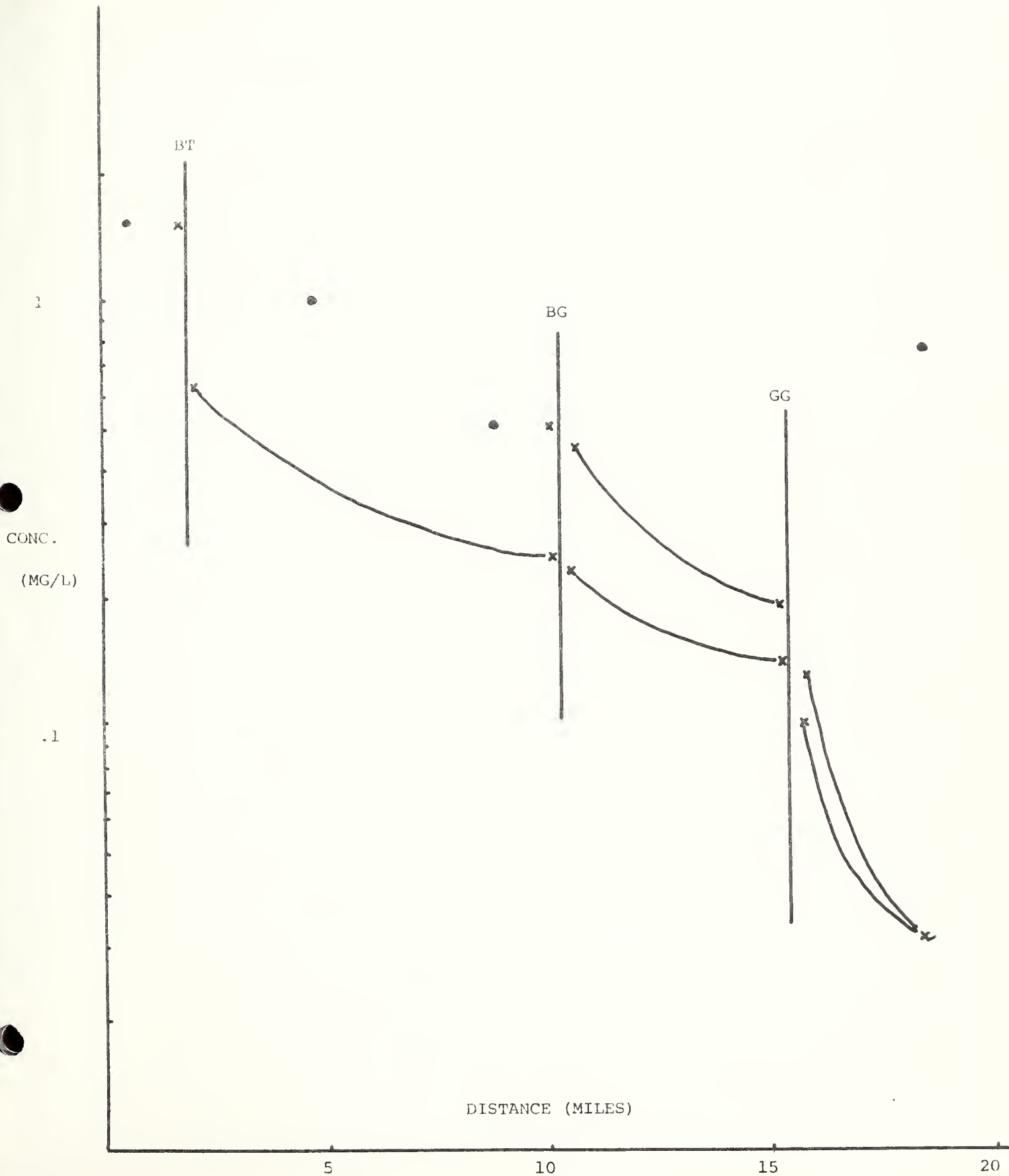


Cu CONCENTRATION (MODEL & AUGUST 1, 1973 STREAM DATA) IN SILVER  
BOW CREEK WATER FROM IT'S INTERSECTIONS WITH BLACKTAIL CREEK (BT),  
BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS





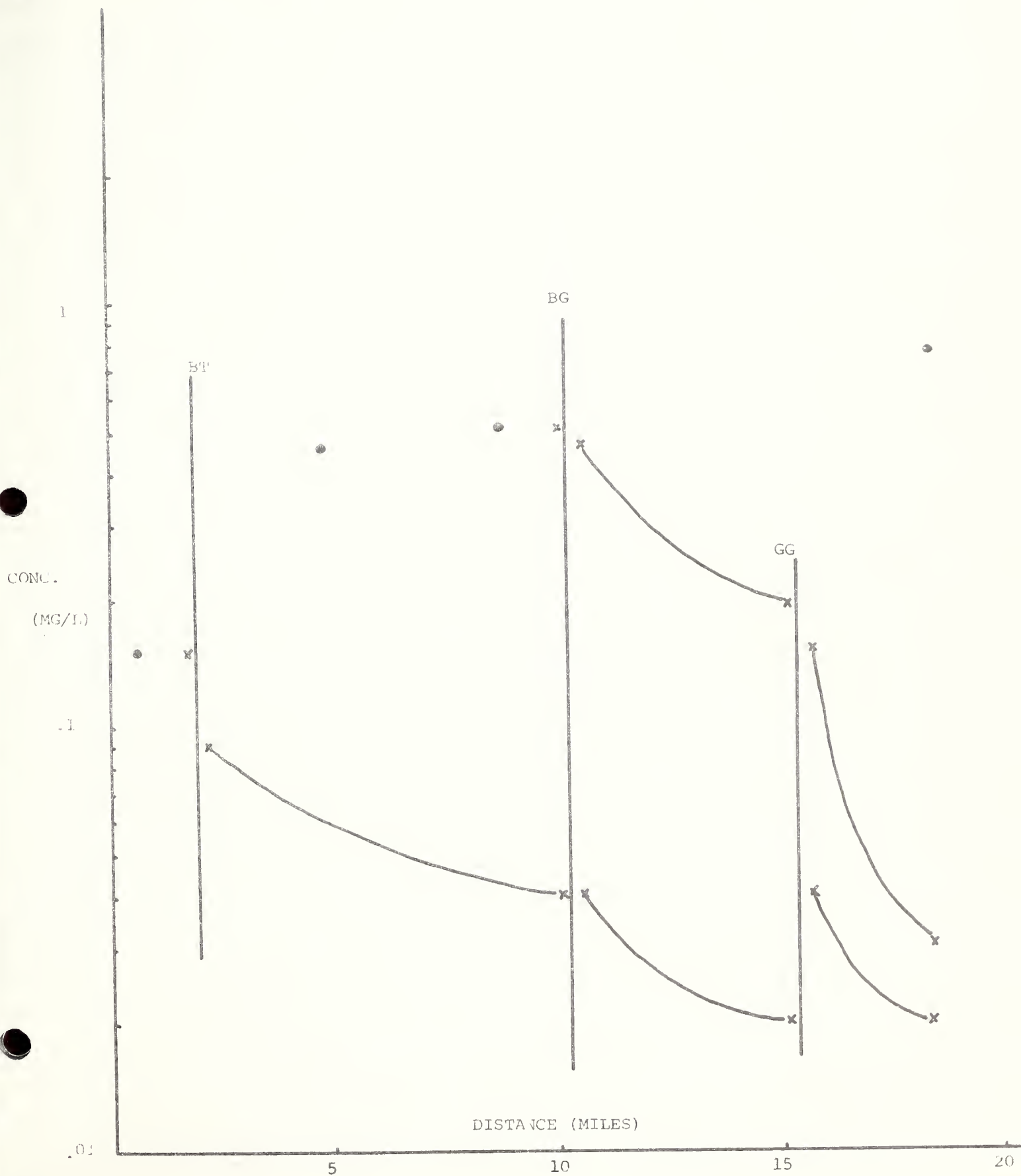
Cu CONCENTRATION (MODEL & AUGUST 7, 1973 STREAM DATA) IN SILVER  
BOW CREEK WATER FROM IT'S INTERSECTIONS WITH BLACKTAIL CREEK (BT),  
BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS



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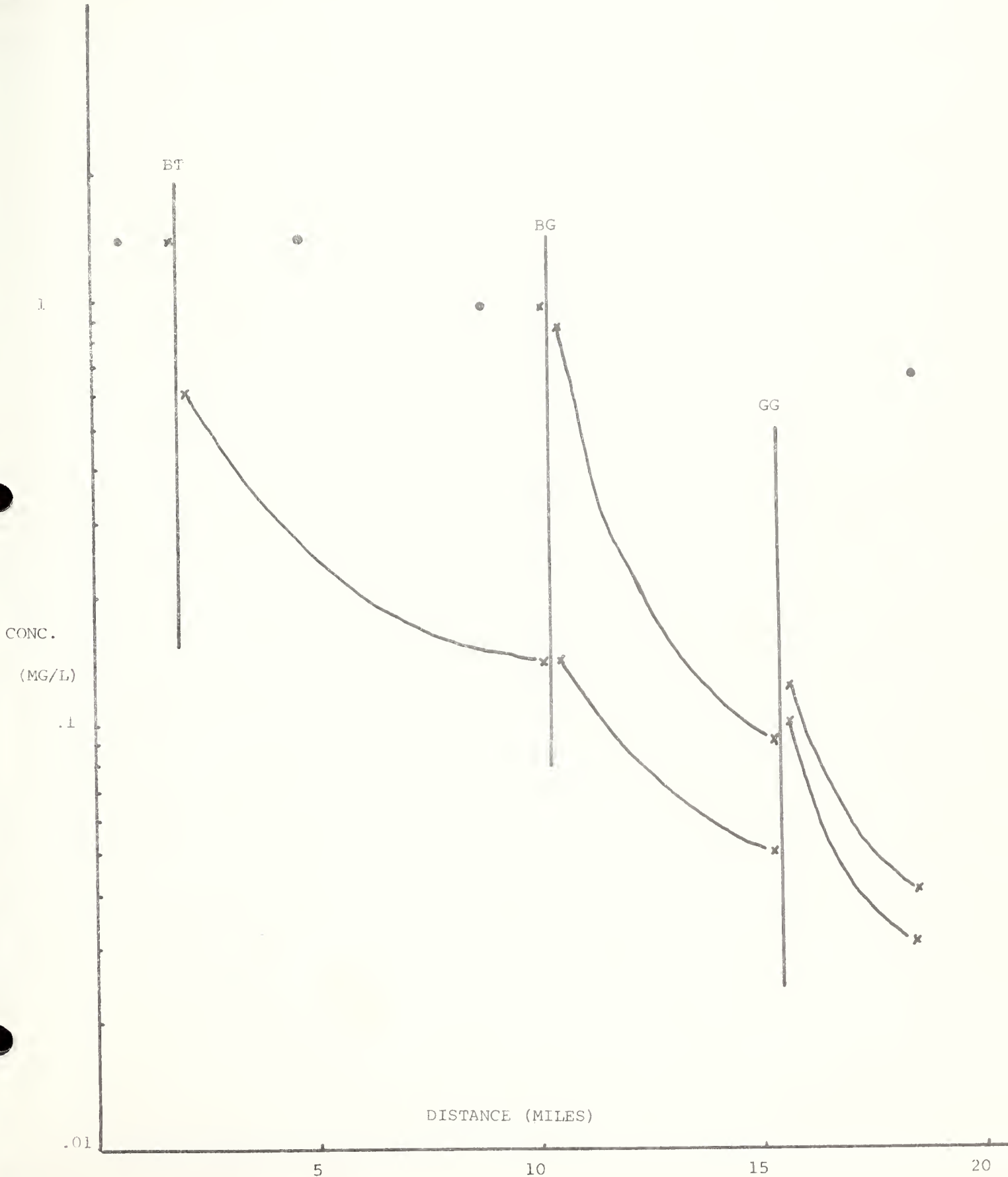


Cu CONCENTRATION (MODEL & AUGUST 14, 1973 STREAM DATA) IN SILVER  
BOW CREEK WATER FROM IT'S INTERSECTIONS WITH BLACKTAIL CREEK (BT),  
BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS





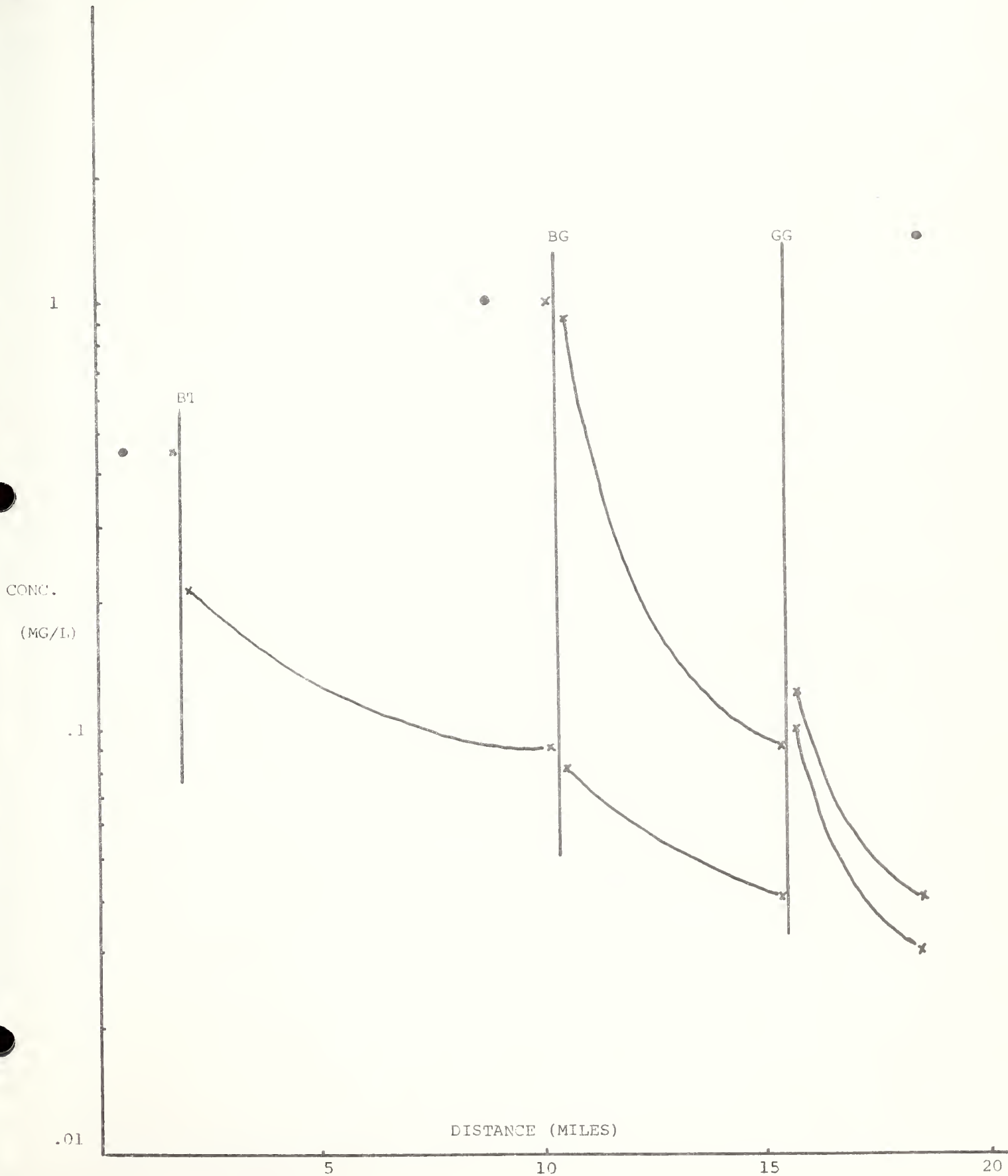
Zn CONCENTRATION (MODEL & AUGUST 1, 1973 STREAM DATA) IN SILVER  
BOW CREEK WATER FROM IT'S INTERSECTIONS WITH BLACKTAIL CREEK (BT),  
BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS



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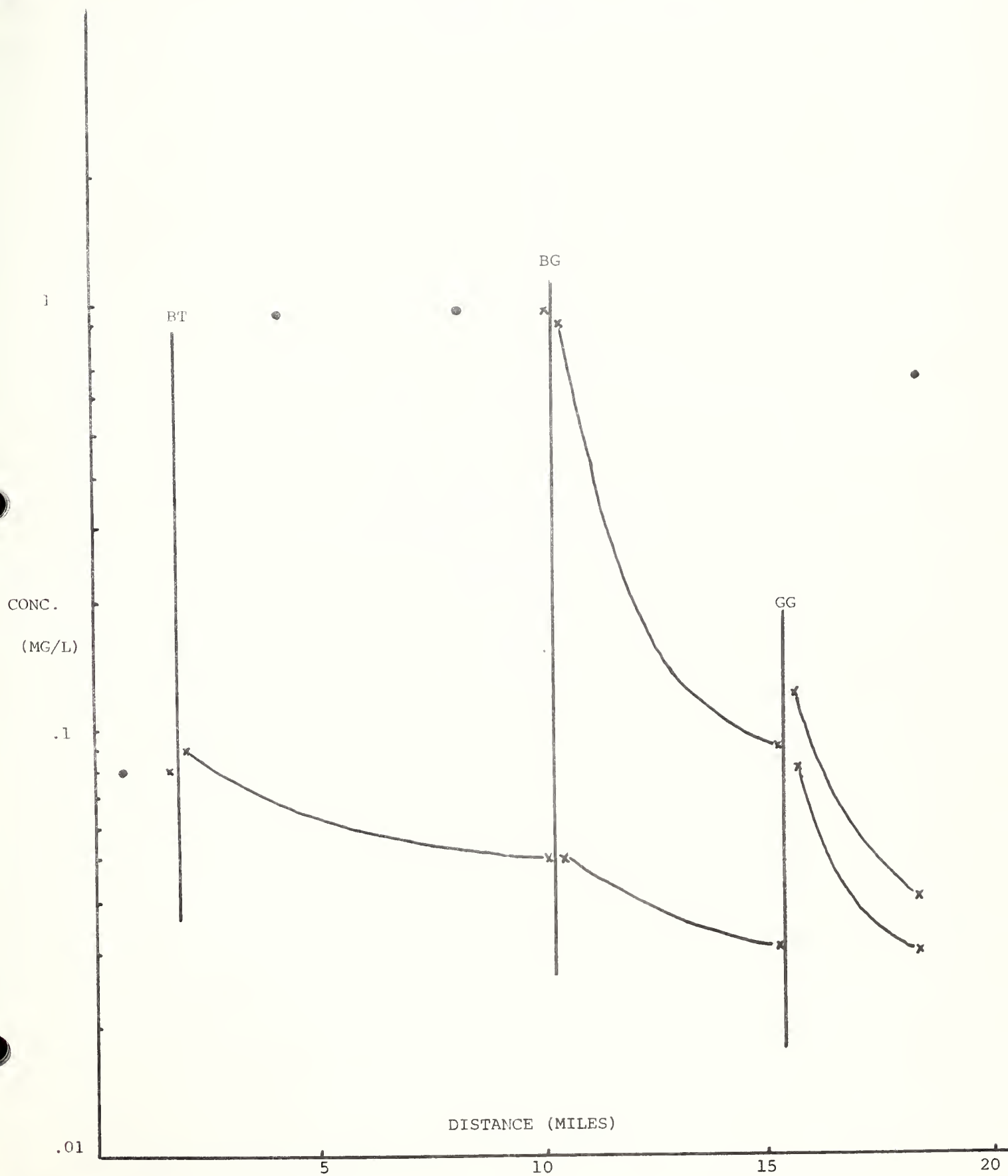


CONCENTRATION (MODEL & AUGUST 7, 1973 STREAM DATA) IN SILVER  
BOW CREEK WATER FROM IT'S INTERSECTIONS WITH BLACKTAIL CREEK (BT),  
BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS





Zn CONCENTRATION (MODEL & AUGUS' 14, 1973 STREAM DATA) IN SILVER BOW CREEK WATER FROM IT'S INTERSECTIONS WITH BLACKTAIL CREEK (BT), BROWN'S CULCH (BG), AND GERMAN CULCH (GG) TO THE SETTLING PONDS





Mn CONCENTRATION (MODEL & AUGUST 14, 1973 STREAM DATA) IN SILVER BOW CREEK WATER FROM ITS INTERSECTIONS WITH BLACKTAIL CREEK (BT), BROWN'S GULCH (BG), AND GERMAN GULCH (GG) TO THE SETTLING PONDS

